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CONTENTS

Synthesis of Boranilide and its Derivatives: Theories on the formation of the Condensation-products.

BY

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Introduction.

It is well-known that anilides are an important class of compounds of physiological importance and therapeutic value. The anilides of organic acids alone have hitherto attracted much attention. The chemical constitution and physiological action of this series of compounds have however been studied in detail by Gibbs and Hare (*Am. Chem. Jour.*, *11*, 435, 1890) and by Gibbs and Reicher (*Ibid*, *13*, 180, 1891).

Dittie prepared the salt of aniline with boric acid as far back as 1888; the aniline borate being a salt of weak base with a weak acid was found to be unstable and easily decomposed by water. Schiff describes a compound (*A. Suppl.*, *5*, 209) as "anilide of boric acid" prepared from ethyl borate and aniline, this "anilide" being easily and readily decomposed by water. It appears that Schiff's compound, as prepared from ethyl borate, was not an anilide but identical with Dittie's compound. The writer has studied (Chaudhuri, *Trans.*, *117*, 1081, 1920) the condensation of aniline with boric acid.

It was believed that if boric acid which is a well-known antiseptic and diuretic and has got both internal and external medicinal use, could be combined with aniline in the form of boranilide, the boranilide so expected,

may have important physiological and hence medico-industrial significance. It is with this object in view that the study of condensation of aniline with boric acid was at first undertaken by the writer and further study in the direction has since been made. From perfectly stable boranilide which has been so obtained, a series of derivatives has been prepared.

Theories on the Mechanism of Condensation.

In the present work molecular quantities of boric acid and aniline are thoroughly pestled together and then heated at 135°—140° C; small quantity of zinc chloride is used as a condensing agent. Aniline does not, however, condense with orthoboric acid. This is due to the fact that at 100° C orthoboric acid is converted into metaboric acid:

$$B(OH)_3 \xrightarrow[-H_2O]{} HOBO$$

with the elimination, as indicated, of one molecule of water; so that condensation at the above temperature (135°—140°C) actually takes place between aniline and meta-boric acid.

The mechanism of the condensation of aromatic amines with other compounds, due to the function of zinc chloride, has been the subject of much study. Reddelien has studied the action of zinc chloride as a condensing agent (*Ann.*, 388, 165, 1912). During the condensation of aromatic amines with aromatic ketones to form anils, the zinc chloride, according to him, forms an additive double compound with the amine as $(H_2NPh)_2.ZnCl_2$, accompanied by evolution of heat and steam. This double compound has been isolated in some cases. According to Reddelien, condensation is due, not to the direct action of $ZnCl_2$ itself, but to the catalytic influence of the

intermediate double compound. It seems at the same time unlikely, however, that the double compound can be the cause of the elimination of water during condensation. According to the views of Dimroth and Zoeppritz, on the other hand, the formation of benzophenone anils occurs in two stages :—

$$H_2NPh + OCPh_2 \longrightarrow PhNH\ (OH)\ CPh_2$$

which has been isolated as its hydro-chloride; the free compound, being unstable, loses water giving rise to the anil :—

$$PhNH\ (OH)\ CPh_2 \xrightarrow[-H_2O]{} PhN{=}CPh_2$$

Coupling the Dimroth-Zoeppritz view with that of Reddelien, the formation of anil appears to be the result of four successive reactions, when $ZnCl_2$ is used as a condensing agent. Reddelien's additive compound, produced at the outset, combines with ketone to form a more complex additive compound at the second stage which, at the third, reacts with the amine giving rise to the enolic form, and this, with elimination of water, finally results in the anil, as indicated below :—

$$(1)\quad ZnCl_2 + H_2NPh \longrightarrow \underset{\text{(Reddelien's Compound)}}{(H_2NPh)_2 \cdot ZnCl_2}$$

$$(2)\quad OCPh_2 + (H_2NPh)_2 \cdot ZnCl_2 \longrightarrow \begin{array}{c} OCPh_2 \\ \vdots \\ ZnCl_2 \\ \vdots\,\vdots \\ (H_2NPh)_2 \end{array}$$

$$(3)\quad \begin{array}{c} OCPh_2 \\ \vdots \\ ZnCl_2 + H_2NPh \\ \vdots\,\vdots \\ (H_2NPh)_2 \end{array} \longrightarrow PhNH(OH)CPh_2 + \underset{\text{(Dimroth-Zoeppritz Compound.)}}{(H_2NPh)_2 \cdot ZnCl_2}$$

$$(4)\quad PhNH(OH)CPh_2 \xrightarrow[-H_2O]{} PhN{=}CPh_2$$

Applying the joint Reddelien-Dimroth-Zoeppritz views to the present case of condensation of metaboric acid with aniline and assuming metaboric acid (HOBO) to possess the group (-BO) which is found to persist throughout the series of boric-amine condensation, the distinct stages leading finally to the product, metaboranilide, may be represented as follows :—

(1) $H_2NPh + ZnCl_2 \longrightarrow (H_2NPh)_2 \cdot ZnCl_2$

(2) $$(H_2NPh)_2 \cdot ZnCl_2 + OBOH \longrightarrow \begin{array}{c} OBOH \\ \vdots \\ ZnCl_2 \\ \vdots\,\vdots \\ (H_2NPh)_2 \end{array}$$

(3) $$\begin{array}{c} OBOH \\ \vdots \\ ZnCl_2 \\ \vdots\,\vdots \\ (H_2NPh)_2 \end{array} + H_2NPh \longrightarrow HO\ B(OH)\ HNPh + (H_2NPh)_2 \cdot ZnCl_2$$

(4) $HO\ B\ (OH)\ HNPh \longrightarrow HOB{=}NPh + H_2O$

It appears, however, that the present boric-amine condensation may be more simply explained by making the natural assumption of the formation of an intermediate additive salt of aniline with metaboric acid, zinc chloride acting simply as a dehydrating agent, helping the abstraction of one molecule of water. As in the case of the formation of acetanilide from aniline acetate, in this case probably unstable aniline metaborate is formed which, at the temperature of the reaction in the presence of $ZnCl_2$, loses water producing metaboranilide [1] :—

(1) $Ph\ NH_2 + HBO_2 \longrightarrow Ph\ NH_2 \cdot HBO_2$

(2) $Ph\ NH_2 \cdot HBO_2 \longrightarrow Ph\ NHBO + H_2O$

[1] [The prefix, *meta* in metaboric acid will not be used in the nomenclature of of the aniline of this acid, in order to avoid confusion in the case of the designation of ortho, *meta* and para derivatives of the aniline.]

Without the addition of $ZnCl_2$, the condensation proceeds very unsatisfactorily; in cases where, at the outset, the condensation takes place without $ZnCl_2$ at a temperature at which the co-existence of the re-acting masses is possible, the condensation is never complete in one direction, as a state of equilibrium results:

$$Ph\,NH_2 \cdot H\,BO_2 \rightleftarrows Ph\,NHBO + H_2O$$

But on adding fused $ZnCl_2$ which has a tendency to remove the molecule of water, the elimination of water is at once facilitated which, as soon as liberated, goes out of the sphere of action at the temperature of the condensation (135° C—140° C); and the system of equilibrium being now disturbed or tilted in one way, the reaction is favoured towards the forward direction. Without, therefore, any assumption of the mysterious intervention of the catalytic function of complicated intermediate compound according to the Reddelien-Dimroth-Zoeppritz views of the mechanism of ketone-amine condensation, the power of a small quantity of $ZnCl_2$ to convert comparatively large quantities of reacting substances into a condensed product may thus be explained.

General Procedure followed.

In the case of boranilide and its derivatives, the presence of boric acid residue has been qualitatively identified in each case. In some cases continued boiling with moderately strong sulphuric acid gave free boric acid, while in other cases free boric acid could only be obtained by heating the compound under examination with sulphuric acid and solid potassium dichromate; and when this was followed by an addition of ethyl alcohol, the alcohol burnt with the characteristic green flame. As the condensation-products are very stable, it appears they are produced by the direct linking of nitrogen and boron,

and not by the inter-linking of oxygen in which case the compounds would have been more easily hydrolysed, and that the linking between nitrogen and boron is of a firmer character.

The well-known glycerol method for quantitative estimation of boric acid produced by decomposition in the present case, did not give satisfactory results. The estimation of carbon, although done with precaution, was vitiated by the absorption of some volatile boric acid in the potash bulbs. But the determination of molecular weight of the first condensation-product, boranilide, from analysis of its double platinic chloride as well as the estimation of nitrogen by Dumas' method conclusively show that the condensation takes place between equimolecular quantities of boric acid and aniline as stated before. The percentage of nitrogen supports the mol.-wt. arrived at from the analysis of the platinic salt.

Boranilide satisfactorily answers Tafel's colour reaction (*Ber.* 25, 412) and Liebermann's well-known nitroso-reaction.

Tautomeric Forms of Anilides.

The anilidic constitution of boranilide receives confirmation from the preparation of nitroso and other derivatives from it, exactly in expected directions. It appears, therefore, that the free anilide as well as the anilide in acid solution has the imino-constitution—

$$C_6H_5NHBO$$

When, however, the anilide dissolves in caustic potash solution its enolic constitution is probably favoured :—

$$C_6H_5NHBO \longrightarrow C_6H_5N{=}BOH$$

owing to the wandering of the iminic hydrogen atom to the oxygen ; and it is due to this tautomerism that the

hydroxylic hydrogen is now replaced by potassium, this having a pinkish colour. The tautomeric deportment of the hydrogen-atom contiguous to *boronyl* group (-BO) in the present case, appears to be analogous to the behaviour of an atom of hydrogen contiguous to heavier atoms in carbonyl and nitrosyl groups; cases of the former are well-known, while instances of the latter are observed in such compounds as benzenediazotic acid and its potassium salt, the anilide of benzenediazotic acid which is transformed into its isomeric aminoazo-benzene and also in some well-known cases of Hantzsch's pseudo-acids.

Experimental.

Boranilide.

C_6H_5NHBO

Thoroughly mixed 5 grams of boric acid with 7·5 grams of aniline; and the mixture was heated in a hard glass test-tube at 135°—140° C on oil bath. Small quantity of (1 gram) fused zinc chloride was then added and the mixture stirred. The pasty contents soon formed a hard mass which was extracted with water, adding small quantities of water at a time. It was then filtered, washed with very dilute hydrochloric acid to remove any free base and then repeatedly washed with warm water. It dissolves in hot alcohol from which it crystallises as white needles belonging to the cubic system. Yield 6·5 grams. Does not melt at 212° C. Mol. wt. 119·7 from analysis of double platinic chloride, taking Pt = 195·0; M. W. calculated for C_6H_6NBO = 119·0. Found N = 11·32%; Theoretical N = 11·76%.

It dissolves in acids and in caustic potash solution.

Benzoyl-boranilide.

$$\begin{array}{l} C_6\,H_5\,N-BO \\ \quad\quad\;\; | \\ \quad\quad OC\,C_6\,H_5 \end{array}$$

This compound has been obtained under two different conditions :—

(*i*) Boranilide is dissolved in glacial acetic acid and benzoyl chloride is then added, and the mixture shaken. A granular precipitate which, when washed and dry, is a fine white powder. M. P. 166°C. Found C = 69·59%, H = 4·87% ; Theoretical C = 69·95%, H = 4·48%.

(*ii*) To 6 grams of boranilide added 7 grams of benzoyl chloride in which the anilide dissolves gradually, but on adding a solution of caustic potash to the mixture and shaking, a granular stuff is immediately produced. This, when washed and dry, forms a white powder. M. P. 165°—167° C.

Thioboranilide.

$$C_6H_5NHBS$$

This compound has also been prepared in two ways :—

(*i*) Intimately mixed boranilide with excess of resublimed flower of sulphur and heated to melt sulphur when the anilide also dissolved in it. The mixture was heated for 10 mts. A very hard solid substance was produced which was powdered and repeatedly washed with warm carbon bisulphide. Yellowish grey powder was obtained, smelling faintly somewhat like mercaptans. It is insoluble in water, alcohol and ether, but soluble in acids. M.P. 109°—110° C. Found N = 9·91%, N. Calc. for $C_6\,H_6$ NBS = 10·37%.

(*ii*) Boranilide mixed with phosphorus pentasulphide is heated in a test-tube. Repeatedly boiled the substance with water for washing and then washed with CS_2 when hard yellowish grey mass remained which is powdered and again washed. It also smells like the preceding compound as obtained under (*i*) M.P. 110° C. sharp.

Nitroso-boranilide.

$$\begin{array}{c} C_6H_5N-BO \\ | \\ NO \end{array}$$

Dissolved boranilide in excess of hydrochloric acid and then added to it a solution of sodium nitrite. A reddish yellow oil is produced which solidifies, on shaking and allowing it to stand, to a brownish pink solid. On adding alcohol, the oil is more readily converted into crystalline plates. It dissolves in ether, and the ethereal solution answers Liebermann's reaction. M.P. 83° C. Found N = 18·22%, $C_6H_5N_2BO_2$ requires N = 18·91%

Hydrochloride of Boranilide.

It is obtained by dissolving boranilide in excess of moderately strong hydrochloric acid and evaporating the solution on water-bath. Greenish thin plates; decomposes at 108° C°. Cl estimated as silver salt = 22·40%, Theoretical Cl = 22.82%.

Double Platinic Chloride of Boranilide.

This has been prepared by first dissolving boranilide in moderately strong hydrochloric acid and then adding platinic chloride solution, when tiny shining yellow crystals came out. The dry crystals, being bottled up, gradually became greenish and perfectly green in about eight months. Found Pt = 30·28%, Theoretical Pt = 30·02%.

Bromo-boranilides.

$C_6H_4Br\,NHBO$

These have been prepared by the action of bromine on boranilide solution in different solvents and conditions as described later. Three compounds, having different melting points, have been obtained. From experience of the melting points of ortho-, meta- and para-compounds, the compound having the highest M.P. amongst the three, has been taken to be the para-bromo-derivative, that having the lowest M.P. to be ortho-bromo-derivative while that having M.P. intermediate between the two, to be the meta-compound, while the estimation of bromine shows that they are isomeric. That these three compounds are ortho-, meta- and para-derivatives of boranilide follow from the well-known empirical rule of Crum Brown and Gibson (*B.* *23*, 130 ; *B.* *25*, *R.* 672).

p—Bromo-boranilide.

A white powder with a pinkish tinge is produced by the action of bromine in an acetic acid solution of boranilide and is filtered. On shaking with chloroform, a perfectly white powder remained which is found to be an acetate, soluble in water. The aqueous solution being warmed with potassium carbonate solution gave the free compound. M.P. 121°–122° C. Found Br=39·86%. Theoretical Br=40·44%.

o—Bromo-boranilide.

This was recovered, by evaporating the chloroform solution obtained from the preceding experiment, as a light pink-colour powder. This is dissolved in water and the solution warmed with potassium carbonate when a very faintly yellow substance separated. M.P. 82°C. Found Br=40·14%.

m—Bromo-boranilide.

This is prepared by first dissolving boranilide in strong sulphuric acid and by the direct action of bromine in the presence of sulphuric acid. Sandy minute crystals, looking almost black are produced. This is dissolved in water and boiled with potassium carbonate when m-bromo-boranilide separated as a violet powder. M.P. 96° C. Found Br=40·01%.

Conversion of Meta into Ortho and Para-bromo-boranilides.

Without separating the sandy, almost black, crystals from contact with sulphuric acid and on boiling this meta-bromo-derivative for a short time with water, a sudden change takes place when the black substance is converted into a slightly pink powder. This pink powder is gently warmed with chloroform when a perfectly white substance remains which dissolves in water. The aqueous solution, boiled with potassium carbonate solution, yields a compound (M.P. 120°–122°C) which is evidently the para-bromo-boranilide, while the chloroform solution, on evaporation, gives a substance from which, when boiled with potassium carbonate, a pinkish powder (M.P. 83°-84°C) is produced which is also evidently the ortho-bromo-derivative.

Benzoyl p-bromo-boranilide.

$$\begin{array}{l} C_6H_4Br\,N-BO \\ \qquad\quad\;\; | \\ \qquad\quad OCC_6H_5 \end{array}$$

p-Bromo-boranilide is dissolved in glacial acetic acid to which freshly prepared benzoyl chloride is gradually added when the solution becomes turbid. On shaking and allowing to stand, white needle-shaped crystals are

deposited. The crystals, when examined under the microscope, are found to belong to the cubic system. M.P. 128°-130°C. Found Br=25·82%, Theoretical requires Br=26·51%.

The preparation of the benzoyl derivative of ortho- and meta-compound has not been tried.

Boranilido-diazobenzene.

$$\begin{array}{l} C_6H_5N-BO \\ \qquad\quad | \\ \qquad\quad N=N\ C_6H_5 \end{array}$$

To 5 grams of nitroso-boranilide 3 grams of aniline is added, and then alcohol-ether containing strong hydrochloric acid is added to the mixture. On boiling the mixture, no action apparently takes place; but on adding water and boiling, the solution becomes red with the separation of a heavy oil which, on cooling and being shaken, soon solidifies to crystalline red plates. M.P. 109°C. It does not answer Liebermann's reaction which shows that (—NO) group is absent and also that the compound is produced by the condensation of a molecule of the nitroso-compound with a molecule of aniline owing to the interaction between nitrosylic oxygen and hydrogen of the amino group;

$$\begin{array}{l} C_6H_5N-BO \\ \qquad\quad | \\ \qquad\quad NO+H_2N\ C_6H_5 \end{array} \longrightarrow \begin{array}{l} C_6H_5N-BO \\ \qquad\quad | \\ \qquad\quad N=NC_6H_5 \end{array}$$

Above 130° C, the compound suddenly decomposes with a feeble explosive noise. During combustion by Dumas' method the burners below the mixture of substance and copper-oxide as well as a little in front of and behind it, are kept very low. Inspite of this precaution, lower result for nitrogen has been obtained owing to rather sudden evolution and consequently incomplete

reduction, of the oxides of nitrogen. Found $N = 18{\cdot}13\%$ Calc. $N = 19{\cdot}29\%$.

Boranilido-hydrazobenzene.

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad HN-NH\,C_6H_5 \end{array}$$

On adding stannous chloride and hydrochloric acid or zinc and hydrochloric acid to the red alcoholic solution of boranilido-azobenzene, the red solution soon becomes colourless owing to the reduction of the azo-compound into the corresponding hydrazo-compound as follows :—

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad\;\; N=NC_6H_5 \end{array} \longrightarrow \begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad HN-NHC_6H_5 \end{array}$$

The mixture is made alkaline. The white hydrazo-compound which is soluble in ether is separated by this solvent. It gives a yellow nitroso-derivative which satisfies Liebermann's reaction. It dissolves in hydrochloric acid. M.P. 123°-124° C.

Boranilido-diaminobenzene.

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad HN-C_6H_4NH_2 \end{array}$$

When a solution of 4 grams of boranilido-hydrazobenzene is boiled in strong hydrochloric acid, a well-known isomeric change called *Semidine conversion* takes place during which boranilido-hydrazo-compound is transformed into the above aminoazo-benzene as follows :—

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad NH-NHC_6H_5 \end{array} \longrightarrow \begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad HNC_6H_4NH_2 \end{array}$$

On boiling the hydrochloride with ammonia, the free base separates. It is a greyish yellow compound soluble

in alcohol ; yield 3·4 grams. M.P. 163°—166° C. Found N = 17·97%. Theoretical requires N = 18·66%.

Boranilido-amino-azo-phenol.

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ \quad HN\;C_6H_4N=N-C_6H_4OH \end{array}$$

4 grams of boronyl amino-azobenzene hydrochloride is dissolved in water, cooled with ice, and then diazotised and coupled with alkaline, nearly 2 grams, of phenol. A brown stuff is produced as follows :—

$$\begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ HN-C_6H_4N=N.Cl+C_6H_5OH \end{array} \longrightarrow \begin{array}{l} C_6H_5N-BO \\ \quad\;\; | \\ HNC_6H_4N=NC_6H_4OH \end{array}$$

It is slightly soluble in cold water, more soluble in alcohol, but dissolves readily in acids and caustic alkalis which points to the presence of the basic and phenolic groups. M.P. 152°-153° C. The substance melts to a deep violet liquid. Yield 5·4 grams nearly.

The hydrochloride of the compound crystallises in dark brown needles.

Dibenzoyl boranilido-amino-azophenol.

$$\begin{array}{llll} C_6H_5N-BO & & & \\ \quad\;\; | & & & \\ \quad\;\; NC_6H_4N=NC_6H_4O & & & \\ \quad\;\; | & & \quad\;\; | & \\ \quad OCC_6H_5 & & OCC_6H_5 & \end{array}$$

The well-known Schotten-Baumann reaction is now applied for the benzoylation of the preceding compound. 5 grams of boranilido-amino-azophenol is dissolved in a small quantity of hot alcohol ; nearly 4-5 grams of benzoyl chloride is added and the mixture shaken. On now adding caustic potash solution to the mixture, and

on warming and shaking, slightly brownish stuff in lump separates. It is insoluble in water, slightly soluble in alcohol, but readily dissolves in ether from which it crystallises in the form of conjugated needles. Yield 8·2 grams. M.P. 113°-115° C.

It may be noted here that the possibilities of successfully preparing boranilide on a large scale seem fair. Besides its value as a new chemical, for the expected therapeutic properties of this compound or some derivative of it which might be anticipated from an analogy with the physiological effects of other anilides, it may be hoped to be of some service to the medico-chemical world as well. It has, however, been found that a satisfactory economic method for the manufacture of boranilide would consist in the application of a special process of auto-condensation.

The Scattering of Light by Solid Surfaces

By

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CONTENTS :

(1) *Introduction.*

When a beam of light falls on a transparent body, besides the usual phenomena of reflection, refraction and internal scattering, a small but appreciable fraction of the light is also scattered by the bounding surfaces in all directions. That this phenomenon has been found to be a characteristic property of every solid and liquid surface in our laboratory was announced by Dr. Raman in a preliminary communication to "Nature," August 25, 1923. Since then detailed experimental work concerning the nature of the intensity and polarisation of the scattered light in different directions has been done on the subject with crystalline and amorphous solids, solid metals, liquid mercury, and a large number of liquids. In a paper * recently communicated to the Royal Society Schuster points out that "the light which enters the optically rarer medium at or beyond the critical angle is an effect of diffraction originating near the boundary of the

* "Nature," November 22, 1924, p. 772 (see 'note' at the end of the paper).

refracting surface." This is easily seen to be a special case of the phenomenon which forms the subject of this paper. This field of work is extremely interesting as it throws light on the nature and disposition of the molecules at the surface of a body.

In the present paper a detailed description of the experimental results obtained in the case of solid substances is given, the work on liquids forming the subject for a separate paper.

(2) *Scattering by Transparent Crystals.*

In the ordinary treatment of optical problems on the electromagnetic theory, the reflection of light at a surface is explained as arising from the difference of the properties of the media on the two sides of the boundary. From a molecular point of view, on the other hand, reflection may be regarded as due to the secondary radiation from the electric doublets induced by the infalling waves in the molecules near the boundary forming a regular wave-train which travels back towards the source. The simplest case to consider is that of a transparent crystal bounded by a plane face where the doublets occupy fixed positions in a space lattice and are disposed in a periodic manner on the surface. It is then easily seen that the effect of the secondary radiations in the first medium disappears by interference in all directions except that of the regular reflection from the surface. Theory thus indicates that when light waves fall on the cleavage face of a transparent crystal, we should have only regular reflection and no scattering at the boundary.

A convenient substance for the study of the phenomenon is mica which cleaves easily and gives an ideal surface free from ups and downs larger than a few light waves. Freshly cleaved mica, when placed at the focus of a short-focus lens of large light-gathering power, fails to show any blue opalescence at the surface except some diffraction effects due to dust or

striae. It is very difficult to keep the surface of the mica fresh for any length of time as the dust in the air is caught with wonderful rapidity. The actual difficulty in observing the surface opalescence, if any, is due to the strongly lit-up dusty tracks of the incident, reflected and refracted beams, which appear like a cross, the centre of the cross being the spot on which the light falls on the mica surface. To avoid this trouble two jets of dust-free carbon-di-oxide or air were directed against the spot from either side so as to get clean, dust-free tracks which would not prevent the surface effects from being observed. Even this was insufficient as the background was not very satisfactory. The defect of the background was got over by using a fairly large wooden cross tube provided with suitable apertures and a thoroughly blackened green bottle for the background. Any chinks left were covered up very carefully with black velvet cloth. With this arrangement, when a slow current of dust-free oxygen was maintained through the cross-tube to keep out dust, the polarisation of the oxygen track could be measured with great ease. A freshly cleaved piece of mica was introduced into the centre of the cross-tube through a narrow slot above and light focussed on it. The reflected light was carefully adjusted so as not to interfere with the background in any way. Even under such excellent conditions no sign of any scattering by the surface could be detected. When a piece of coloured mica was tried, however, a feeble blue spot could be seen. It was at first presumed to be the scattering by the surface; but on introducing pieces of increasing thickness the spot was observed to increase in intensity showing thereby that the apparent surface effect is really due to the molecules of the colouring matter inside the mica. An examination of the blue spot with a microscope does not reveal any structure. This experiment confirms the expectation from theory that the irregularities of the surface due to thermal agitation are negligible so far as our present phenomenon is concerned.

Pieces of clear quartz cracked under controlled static compression were next examined with light focussed by a microscope objective which gave a very intense focus. The surface of the conchoidal fracture was so irregular and the most carefully made crack so full of fine quartz dust that the observations failed to reach any definite conclusion. Sometimes by chance, clear portions against a tolerable background could be secured which showed no scattering. It may as well be remarked now that it is impossible to make a given surface sufficiently clean for the observation of surface scattering by any chemical or physical methods. Washing with acids, alkalis and distilled water, etc., however carefully done, leave some kind of dirt or other which show very intense spots when placed at the focus of the beam of light. Starting with a freshly cleaved surface, the influence of these methods of cleaning can be studied. The intensity after chemical cleansing is thousand times greater than what it was before.

Besides quartz, crystals of calcspar, rock-salt, etc., were tried ; but the cleaned surfaces are indeed too poor in quality. On the whole, the above experiments indicate that the surface opalescence in the case of crystals is extremely small.

In the case of a clear block of ice, when light is focussed on the surface, a very intense spot is shown up by the melting surface. If the water formed is blown away by a jet of oxygen or carbon-di-oxide, a feeble blue surface opalescence is visible. By sufficiently increasing the force of the jet of gas, a stage is reached when the intensity of the scattering does not diminish any further. Under the conditions of the experiment it is difficult to say whether the phenomenon is to be ascribed to the surface of ice or to the incipient film of water which the stream of gas may not be able to remove.

(3) *Scattering by Amorphous Solids.*

Under this heading come the various kinds of glass. We had a very fine collection of the various grades of optical glass

manufactured by Messrs. Schott and Genossen of Jena. Some of these were used in the following experiment.

The specimen to be examined was cracked as before under a screw-press and the fresh surfaces secured examined immediately afterwards. In every case a rather strong and bluish-white opalescence was observed at the surface. When examined by a microscope the focal spot was found to be resolved into very uniformly distributed fine specks just as a fairly thick oil film on water (several molecules thick), when examined in the same way, exhibits microscopic droplets. It is remarkable that the appearance in these two widely different cases is strikingly similar. A description of the distribution of intensity of the scattered light and the nature of its polarisation in different directions is given below.

Let us first take the simple case of unpolarised light normally incident on the surface of glass. The intensity is a maximum in the direction of the normally reflected and the transmitted beams. The intensity rapidly diminishes as the direction of observation is shifted towards the plane of the surface. The spot shows appreciable polarisation in this position when examined with a double-image prism. The stronger component has its electric vector parallel to the surface.

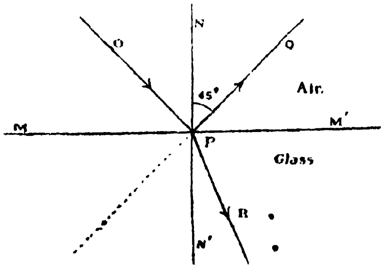

Fig (i).

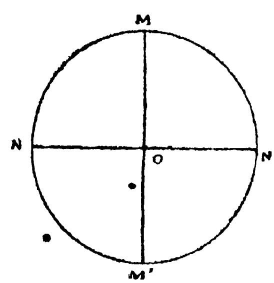

Fig (ii).

When the angle of incidence is 45° and the plane of observation is the plane of incidence (see Fig. i), in directions

near MP, the vertical component, *i.e.*, the one perpendicular to the surface, is slightly stronger. In directions lying between OP and PQ, the component parallel to the surface, *i.e.*, horizontal, is slightly stronger. In a direction near PQ, the reflected ray, the spot is unpolarised. Between PQ and PM the horizontal component increases enormously in brightness until, parallel to M′P, it is completely polarised, the weaker component perpendicular to the surface being exceedingly feeble. On the glass side, in directions lying between PM and PQ′ the horizontal component parallel to the surface is slightly stronger and in directions between PR and PM′ the vertical component is only slightly stronger even when the direction is almost parallel to PM. In the direction PR the spot is unpolarised.

As regards the distribution of intensity, the intensity is maximum along PQ and PR. On the air side it is a minimum along PM and, excluding directions near PQ, more intense along PM′. On the glass side the intensity in every direction is much more than that on the air side and the intensity is more between PR and PM′ than between PN′ and PM.

When the plane of observation is confined to the plane at right angles to the plane of incidence, the intensity of scattering is, as before, maximum in the direction of the reflected and transmitted light. The total amount of light scattered in this plane at even small angles with the normal PN is indeed exceedingly small. In Fig (*ii*) MM′ is the surface of glass held vertically and NN the normal to it. The circle has the opalescent spot O as its centre. MNM′ is on the air side and MN′M′ on the glass side. In the direction OM the light is partially polarised with its stronger component parallel to the surface of the glass and at right angles to the plane of the paper. This polarisation is a maximum for normal incidence and gets less and less as the angle of incidence increases, while the reverse is true in the

direction PM′ in the plane of incidence (see Fig. *i*). On the glass side also the spot shows polarisation with vibrations parallel to the surface and perpendicular to the plane of the paper in directions near OM. Along ON and ON′ it is unpolarised. The above observations bring out the main points of interest with regard to the scattering of light by a surface of glass.

In this connection one observation is noteworthy. In the act of cracking the glass block, some fine glass dust usually clings to some parts of the fresh surfaces and render observations on the air side extremely difficult. All the observations have to be made at some places free from such dust. On the glass side, however, the presence of the dust particles does not at all interfere with the observations. One can always get a clean and fairly intense white spot. This is evidently due to the fact that the particles in question are not in optical contact with the fresh surface of glass (a film of air separates them) and so the light scattered by them into the glass is refracted into a small cone with its axis along the normal to the surface and its half-angle equal to the critical angle for glass. On the other hand the dirt on an old surface or even a grease spot on a fresh surface behaves quite differently, giving as it does a much more intense spot on both sides, the intensity being several hundred times that in the case of the genuine surface effect.

(4) *Scattering by Metals.*

The case of metals is essentially different from that of non-conductors like glass. The nature of the polarisation effects in the case of the solid metals and the ideal liquid mercury surface were found to be very similar. The surfaces were polished with great care and were apparently quite good. Microscopic examination, however, revealed irregularities which are very difficult to get rid of. This is evidently due to the extreme softness of the metals. The metals used were

gold, silver, copper, iron, nickel, zinc, aluminium and brass. With all of them similar results were obtained. The following is a brief description of the experimental results.

The characteristic property of the metallic surface is to scatter normally incident, unpolarised light in directions parallel to the surface with the electric vector of the stronger component perpendicular to the surface. The vibration in the incident beam which is mainly responsible for this lies in the direction of observation.

I. Aluminium (plane of the reflecting surface vertical).

(*a*) *Normal incidence of unpolarised light.*

Observed parallel to the surface with a double image prism, the component with vibrations perpendicular to the surface is very very intense. On moving towards the normal to the surface, the weaker component continues to be weak.

(*b*) *Normal incidence—light polarised with vibrations vertical.*

In the horizontal plane containing the incident beam, when the spot is viewed parallel to the surface with the double image prism, the two components are almost equal, the slightly stronger component having vibrations parallel to the surface, *i.e.*, vertical. The vertical component increases in intensity as the normal to the surface is approached

In the vertical plane at right angles to the surface, viewed parallel to the surface, the component with vibration perpendicular to the surface is distinctly brighter and remains brighter as the normal to the surface is approached.

(c) *Oblique incidence—light polarised with vibrations vertica .*

Observing from every possible direction in the plane of incidence the stronger component has always its vibrations vertical. In the plane at right angles to the plane of incidence, the stronger component has vibrations perpendicular

to the surface when observed parallel to the surface and on moving towards the normal the same component remains stronger, its vibrations while observing normal to the surface being vertical. In all directions in this plane the scattered light is very strongly or almost completely polarised.

When the incident light is polarised with the electric vector horizontal, for all directions of observation in the plane of incidence the stronger component has always its vibrations horizontal. In the other plane the horizontal vibration is only slightly stronger when observing parallel to the surface and in all directions the contrast between the two components is not very marked.

Lastly, when the incident light is unpolarised and the angle of incidence is nearly 85°, the maximum polarisation in the plane of incidence is away from the reflected light with the strong component horizontal and the minimum polarisation is near the reflected light. In the other plane at right angles o the plane of incidence, the stronger component has vibrations normal to the surface when observing parallel to the surface, the contrast between the two components decreasing as the normal to the surface is reached.

II. Copper (plate held vertically).

(*a*) *Normal incidence of unpolarised light.*

Observing parallel to the surface, the stronger component has vibrations normal to the surface and is coloured red, the ratio $\frac{\text{red component}}{\text{white component}}$ decreasing as the normal to the surface is approached.

(*b*) For oblique incidence of unpolarised light in every direction either in or at right angles to the plane of incidence the coloured component, with vibrations normal to the surface when observing parallel to it, is stronger, more so away from the direction of the reflected beam than towards it.

(c) *Light polarised with vibrations vertical.*

For all angles of incidence the coloured component, with vibrations normal to the surface while observing parallel to it, is decidedly weaker when the observations are confined to the plane of incidence. In the plane at right angles to the plane of incidence the stronger component, when the observation is along the surface, has vibrations normal to the surface but is the whiter of the two. The weaker component has a very rich red colour. The ratio of $\frac{\text{strong component}}{\text{weak component}}$ increases as one approaches the direction of reflection.

When the incident light is polarised with its vibrations horizontal, viewing in the plane of incidence, the stronger component has in all directions its vibrations horizontal and remains stronger for all angles of incidence. In the plane at right angles to the plane of incidence the ratio of the component which is coloured and with vibrations normal to the surface on observing parallel to it to the other component approaches unity as the angle of incidence is slowly increased.

III. Iron, zinc and brass also behave like aluminium and copper. In the case of brass, the coloured and stronger component has vibrations normal to the surface and is yellow, the fainter component being bluish.

A concave galvanometer mirror manufactured by Adam Hilger with a gold on quartz surface was tried and found to give results very similar to those given by the other substances. The polish was very much better and the intensity of the scattered light was on that account very small. On observing the opalescent spot with a microscope, although many specks and spots and other irregularities were very prominent, careful observation revealed a general background illumination which could scarcely be mistaken for any other effect other than genuine surface scattering.

Actual measurements of the nature of the polarisation of the scattered light were taken with the help of a double-image prism and a nicol rotating on a graduated circle in the usual way. We give below the results for two typical cases like iron and copper. It must be pointed out that these measurements are not to be taken as final as they have to be verified for metallic surfaces with perfect polish. The present measurements, however, show the general nature of the phenomenon.

I. Iron.

ϕ—angle of observation with reference to the reflecting surface; for grazing incidence $\phi=0$ lies on the side away from the reflected light.

θ—half the difference between the reading of the nicol for the two positions of equality.

$\tan^2\theta$—ratio of the weak to the strong component.

(a) *Normal Incidence of Polarised Light.*

Table I.

ϕ	$\tan^2\theta$ for vertical vibrations.	$\tan^2\theta$ for horizontal vibrations.
15°	·110	
20°	·112	·008
30°	·082	·011
40°	·050	·017
50°	·031	·015
60°	·020	·011
70°	·013	·011

(b) *Grazing Incidence of Polarised Light.*

TABLE II.

ϕ in plane of incidence.	$\tan^2\theta$ for vertical vibrations.	$\tan^2\theta$ for horizontal vibrations.
30°	·072	·038
40°	·072	·045
50	·082	·045
60°	·083	·053
70°	·071	·045
80°	·071	·034
90°	·046	·031
100°	·038	·025
110°	·034	·025
120°	·017	·020
130°	·006	·015
140°	·005	·009
150	·003	·005

(c) *Incidence of polarised light at 45°—Observations in the plane at right angles to the plane of incidence.*

TABLE III.

ϕ	$\tan^2\theta$ for vertical vibrns.—weak comp: is always horizontal.	$\tan^2\theta$ for horizontal vibrns. strong comp: is always horizontal.
15°	·053	1·000
30°	·088	·423
45	·137	·270
60	·160	·189
90°	·180	·133

II. Copper (observations taken with red filter).

(*a*) *Normal Incidence of Polarised Light.*

TABLE IV.

	$\tan^2\theta$ for vertical vibrations	$\tan^2\theta$ for horizontal vibrations.
10°	·528	·031
20°	·490	·038
30°	·361	·041
40°	·283	·049
50°	·198	·049
60°	·147	·039

(*b*) *Grazing Incidence of Polarised Light.*

TABLE V.

ϕ in plane of incidence.	$\tan^2\theta$ for vertical vibrations.	$\tan^2\theta$ for horizontal vibrations.
30°	·336	·125
40°	·250	·123
50°	·230	·123
60°	·211	·112
70°	·185	·106
80°	·130	·088
90°	·130	·058
100°	·084	·045
110°	·067	·034
120°	·036	·031
130°	·030	·030
140° (near reflected ray).	·005	·030

(*c*) *Incidence of polarised light at 45°—Observations in the plane at right angles to the plane of incidence.*

TABLE VI.

ϕ	$\tan^2\theta$ for vertical vibrns. weak comp: is always horizontal.	$\tan^2\theta$ for horizontal vibrns. strong comp: is always horizontal.
15°	·100	·391
30°	·100	·307
45°	·100	·240
60°	·090	·171
90°	·073	·049

(5). *Summary and Conclusion.*

(1) The scattering of light by freshly cleaved surfaces of mica, quartz and other crystals has been found experimentally to be negligible and this is quite in agreement with theory.

(2) The opalescent spot shown up by a freshly cracked surface of an amorphous substance like glass has an intensity much smaller than the intensity in the case of a chemically cleaned surface of the same substance. When examined with a microscope, the spot is resolved into uniformly distributed fine specks very similar in appearance to those seen on an oil film on water when examined in the same way. The nature of the polarisation and the distribution of intensity of the scattered light in different directions has been described.

(3) The scattering by polished metallic surfaces is essentially different from that by a non-metallic surface. The main features of the polarisation effects are described for various metals and the measurements of the polarisation in different directions in the case of iron and copper are given.

The author intends following up the experimental work in connection with metallic surfaces obtained by means of cathode sputtering. The surfaces of thick films of metal obtainable by this method would be much better than those prepared by ordinary polishing and may lead to more reliable and accurate data than those obtained hitherto.

In conclusion, the author wishes to express his best thanks to Prof. C. V. Raman for his valuable help and encouragement.

Note.

While this paper has been in the press, Schuster's paper referred to on page 129 has appeared (Proc. Roy. Soc. Vol. 107, January 1925). Schuster's point of view is now seen to be quite different from that of the

present paper. He has not dealt with the fundamental problem of surface scattering, an effect due to the inherent thermal fluctuations of the surface, but has treated the problem of diffraction of light in the ordinary way arising from the finite width of the incident beam or the finite length of the surface illuminated. In the latter case no special properties of the surface of separation are directly concerned. The effect is wholly due to the geometry of the incident beam and "the ratio of the total energy dissipated into space by diffraction to the total energy of the incident light is inversely proportional to the square root of the length of the refracting surface and therefore tends towards zero as the size of the refracting surface increases." According to Schuster's calculations, the effect in his case is of a much higher order of magnitude than that of surface scattering as may be expected. A more complete discussion is reserved for a later paper.

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Purana group of the Himalayas.

A study in the petrologic method of correlation.

BY

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INTRODUCTION.

The name Purana group was introduced by Sir Thomas Holland in 1906 (8) to include a great thickness of unfossiliferous beds, found both in Peninsular and extra-Peninsular India, lying between the Archaean gneisses and schists on the one hand and the oldest undoubted fossiliferous rocks on the other. These rocks are extensively developed along the central Himalayan belt from the neighbourhood of Attock to the east of the Mishmi country. Detached portions along this zone have been surveyed, the Purana rocks have been mapped in this zone, and, as no fossils have been detected in these, any attempt at correlating them must be based on a similarity of petrological facies and the present paper embodies the results arrived at by the application of this method of study.

To make the points clear it is necessary to recapitulate the characters of the Purana rocks as developed in the different areas and it will be quite profitable to start with the description of the Purana rocks as found developed in the Simla and the Darjeeling region because the rocks of these two areas present peculiarities which are quite distinct from one another. The pre-Tertiary

sedimentary rocks of the Simla region have been distinguished as below (13):—

Krol.

Infra-Krol.

Blini.

Infra-Blini.

The infra-Blini (or Blaini) beds are typical slaty formations; the Blaini beds are characterised at Simla by two boulder-beds separated from each other by a bed of bleach slates and having, at the top, a limestone which is usually pale pink in colour; the infra-Krol beds are typically carbonaceous slates and the Krol beds consist of quartzitic sandstone at the bottom overlain by a band of blue limestone which is separated from another bed of blue limestone lying at the top by a bed of red shale. In the Darjeeling area, two series have been found lying between the gneissose rocks and the Damuda beds (12), *viz.*, the Baxa series and the Daling series. The Daling series consists chiefly of slate, phyllites and quartzites while the younger Baxa series is characterized by a very prominent bed of dolomite.

Simla Facies.

In any attempt at correlating beds which are devoid of fossils it is necessary to find out a bed marked by some peculiarity and take it as the datum-lime for the purpose and in the Punjab Himalayas this is furnished by the Blaini beds. The westernmost exposure of the Purana group in the Himalayas is the rock-formation known as the Attock slate series (23). This series is very well-developed in Hazara and essentially a slaty formation with subordinate limestone and sandstone bands. This slaty series is overlain by the infra-Trias series

consisting of a conglomeratic band at the base. This band appears to be a boulder-clay, though no scratched or striated pebbles have been detected in them as yet, and, as it has been already suggested by Mr. Middlemiss (17), this basal conglomerate may be correlated with the Blaini boulder bed. It appears further that this correlation does not stop here. The topmost member of the Hazara infra-Trias is a bed of limestone of considerable thickness which resembles, to a certain extent, the Krol limestone in its mode of weathering, containing chert and having at the base a bed of sandstone, though it should be pointed out that the red shale of the typical Krol section is missing here. It thus appears that we may arrive at the following relationship between the Purana groups as they are developed in Hazara and the Purana rocks with the Simla facies.

Simla Facies.	*Hazara Area.*	
Krol	Upper limestone sandstone.	Infra-Trias (Middlemiss.)
Infra-Krol	Purple shales.	
Blaini	Basal Conglomerate.	
Infra-Blaini	Attock slate.	

It may be observed that, if the correlation sketched above is correct, the infra-Krol has much thinned out in the Hazara area while the Krol beds have thickened slightly.

The next important outcrop of the Purana group to be noted to the east of these beds is the formation known as the Kangra slate which is the representative of the infra-Blaini slate of Simla (13).

The next tract to be considered is the town of Simla and its neighbourhood, the detailed geology of which was

worked out by Mr. Oldham who arrived at the following result by way of correlation (20):—

Hornblendic rocks	Intrusive.
Upper or Jutogh carbonaceous slates and limestones	Krol shale and limestone.
Boilegaunge quartzite	Krol sandstone.
Lower or Jacko carbonaceous slates ...	Infra-Krol.
Blaini group	Blaini group.
Infra-Blaini beds	Infra-Blaini group.

Let us now consider the Purana rocks as developed in the Kumaun Himalayas. We shall start with the Dehra-Dun or Jaunsar area. For a detailed account of this portion of the Himalayas we are also indebted to Mr. Oldham who, at first, divided the rock systems of Jaunsar into the Mandhali, Deoban and Chakrata series (19), the last name being subsequently replaced by that of Jaunsar. Oldham also recognised a rock system, the Bawar system, which was originally placed by him in the tertiaries, but was subsequently correlated with the Mandhalis. The identity of the Mandhalis with the Blainis has been established by Mr. Oldham beyond any shade of doubt and from this it is evident that the Deoban limestone and the underlying Jaunsar series represent the infra-Blaini stage of the Simla facies. No detailed geological map of the area round about Mussooree has been published as yet. According to Medlicott, the Mussooree rocks are of Krol age (13) while, according to Oldham, along the Mussooree ridge infra-Krols, quartzites, limestone (Krol) and the Blaini are seen (18). I had an occasion sometime ago to spend a few days in studying the rocks developed at Mussooree and was struck by the marked resemblance existing between the rocks of this hill station and those of the Krol and the Bhoj hill. As one begins the ascent from Rajpur, the road passes

through quartzites and slates of various colours, a nice section, due to a slip, being exposed near the road. Traverses in and round about Mussooree leave no room to doubt that we are here dealing with the rocks of the Krol series, the only distinction that is observable between the Krols of Mussooree and of the typical area is that the shale intermediate between the two beds of limestone in the latter has also a thin intercalated limestone band in the former. The same chopping-board weathering and bands of chert found in the Krol limestone are also noticed here. The rocks exposed in the neighbourhood of Rajpur very likely represent the infra-Krol series. Accordingly the following table may be worked out for the Purana rocks of the Dehra-Dun area :—

Krol	...	Mussooree limestone
Infra-Krol	...	Rajpur series.
Blaini	...	Mandhali.
Inra-Blaini	...	Deoban. Jaunsar.

The next area to be discussed is British Garhwal and, as appears from the description of Mr. Middlemiss, the Purana group of this tract consists of the following members (15):—

Massive limestone.
Purple slates and volcanic breccia.

The most remarkable thing to note here is the absence of the Blaini conglomerate, an important datum-line in unravelling the earlier history of the sub-Himalayas. Mr. Middlemiss left the question of the correlation of the massive limestone practically open as, according to him, it might be the Krol or the Deoban limestone. The association of volcanic beds in the Jaunsar series and the general nature of the rocks of this series would undoubtedly

place the Jaunsar series in the same line with the purple slates and volcanic breccia underlying the massive limestone beds: The boundary between the purple slates series and the limestone is not faulted, but is usually a normal unconformable one and, at the same time, the underlying band of quartzitic standstone and the intermediate bed of shale are also wanting. Accordingly I think that this massive limestone agrees more with the Deoban than with the Krol limestone and the whole of the representative of the Purana group in this region is comparable with the infra-Blaini series.

Naini Tal area is next to be dealt with. Medlicott made a very passing reference to the Naini Tal rocks and thought that they might represent the Krol beds of Simla (13). Middlemiss in his comprehensive account of the geology of the Naini Tal region recognised the following sequence of beds in the area (16):—

Massive limestone.
Purple slate series.
Trap (intrusive).

In his report on the geological structure and stability of the hill-slopes around Naini Tal, Sir Thomas Holland gave the following detailed classification of the Naini Tal rocks (7):—

(1) Slates and Shales.
(2) Dolomites.
(3) Dolomitic sandstone.
(4) Purple sandstones and Quartzites.
(5) Dioritic traps.
(6) Gypsum.

It may be noted that the trap is intrusive in the dolomitic and slaty series, while the gypsum is a secondary product formed from the alteration of dolomite. Sir Thomas Holland thinks that the dolomitic limestone of

Naini Tal may be the equivalent of the Deoban Limestone and, from what we have already seen, the rocks of the Naini Tal region may be relegated to the Infra-Blaini.

NEPAL HIMALAYAS.

Coming to the Nepal Himalayas we find that the rocks of the Purana group are developed about Khatmandu and they consist of (14):—

(1) Limestone and quartzite.
(2) Quartzite and schist.

According to Medlicott the upper limestone and quartzite belong to the Krol formation (14) but I think that this correlation is of doubtful value because of the great distance of the Nepal rocks from the easternmost limit of the Purana rocks with Simla facies and of the absence of the Blaini beds which have always been noted in the areas where the undoubted Krol rocks have been found to be developed. From what has been said above, it appears very doubtful if any Krol outcrop will ever be found east of the Mussooree area, and as no case has been recorded of the occurrence of the Krol rocks without the Blaini beds, it is extremely doubtful if these Nepal rocks are representative of the Krol formation. It has been also seen that the infra-Blaini rocks of Dehra Dun and the adjoining areas to the east of it are characterised by an overlying band of limestone and an underlying formation of quartzite and slates. This observation coupled with the opinion of Mr. Medlicott that the 'flaggy quartzite of the lower horizons in the Nepal sections would very fairly represent the thin siliceous beds that form so large a part of the Simla slates, or infra-Blaini Zone' lead one to suggest a correlation of these Nepal rocks with the infra-Blaini series, but this suggestion is also hazardous.

Darjeeling Facies.

After leaving the Nepal Himalayas we come to what have been often described as the Sikkim Himalayas. The best geological account of this area we owe to Mallet (12) while in Freshfield's "Round Kanchinjinga," (3) there is a map with the outcrops of the principal rocks laid down and a short geological note from Prof. Garwood. As already mentioned Mallet distinguished two rock groups—the Baxa and the Daling series—as lying between the Gondwanas and the Darjeeling gneisses and though there was some doubt in Mallet's mind regarding the relative position of the Baxa and the Daling series, it is now clearly recognised that the Baxa series is younger than the Daling. There seems to be some difference of opinion regarding the use of the term Daling. According to Burrard and Hayden, the Daling series has been included under the Archaean group (2), but in the map accompanying their work the Daling outcrops have been shown as quite distinct from the granites and the crystalline schists on the one hand and the Purana rocks on the other. Dr. Maclaren thinks that the Daling series is referable to the Purana group (11), and, according to Dr. Pilgrim, 'the rocks called by Mallet Dalings and Baxas belong to this (Purana) group' (21). From what little I have seen of the Dalings and the Darjeeling gneisses in the Darjeeling area I am led to think that the Dalings are separable from the gneisses and form a part of the Purana group and accordingly we find that in Darjeeling the Purana group is divisible into an upper member—the Baxa series, and a lower member, the Daling series. The Daling series is characterised chiefly by quartzites, slates and schists and the Baxa series contains towards its base a very thick bed (1500′) of dolomite, with interbanded layers of dark-grey slate, while, as it has already been remarked by Mallet, 'the

almost complete absence of lime in the Daling beds is one of the most prominent lithological distinctions between them and the Baxas.' Prof. Garwood has mapped a considerable Daling patch to the N. N. E. of Darjeeling (3). As will be seen later on, the Purana rocks are represented eastwards by these two types of rocks and as they are apparently quite distinct from the rocks of the Simla area, they may be said to represent what may be called the Darjeeling facies of the Himalayan Puranas. In Darjeeling proper, the Baxas have a very limited outcrop, but they have a very considerable development in the Western Bhootan Dooars.

Mallet's map terminates along lat. 90° and there is a considerable gap before we come to the next geologically coloured patch for which we are indebted to Dr. Pilgrim (21). In this area Dr. Pilgrim came across the Purana beds comprising the Baxas and the Dalings, the Baxas being characterised by dolomite. Dr. Pilgrim did not separate the Baxas and the Dalings in the map and the eminent authors of the Geology and Geography of the Himalaya Mountains and Tibet have adopted Dr. Pilgrim's colour, though they evidently do not agree with him in the interpretation of the term Purana. Thus we find that the types of rocks found near Darjeeling and the Western Bhootan Dooars are also repeated in portions of Bhutan to the further east.

The next portion to be considered is the Aka hills of the Assam Himalayas for a geology of which we are indebted to Mr. La Touche (10). The Purana group of this area is characterised by slates and schists of the Daling type and no dolomite has been recorded. So we find that the Purana group is represented in the Aka hills by the Daling series only. The next patch to be noted is the Daphla hills for a geological account of which we are thankful to the late Mr. Godwin-Austen (4).

The Purana rocks are here represented by quartzite, mica-schists, etc., which possibly represent the Daling series.

The next portion of the country to be considered is the Abor country for a geology of which we are indebted to Dr. Coggin Brown (1). In this country the Purana rocks are evidently represented by the following sequence :—

Metamorphic series.
„ (with dolomites).
Mica schists series.

The metamorphic series consists chiefly of slates, quartzites and schists and when we remember that in the typical Baxa section the dolomitic rock occurs nearly at the bottom and is succeeded by a considerable thickness of slaty and schistose rocks we may safely conclude that the upper two members of the Purana group represent the Baxa series and the mica-schist series lying at the bottom represents the Daling series.

We have now to turn our attention to the eastern-most outcrop of the Purana rocks, namely, the Miju range where, according to Maclaren, the Purana rocks are referable to the Daling series and the rocks found are quartzites and slates with phyllites (11).

AGE OF THE PURANA ROCKS—SIMLA FACIES.

From what has been said above it is clear that in the Purana rocks of the Himalayas two distinct facies can be recognised each being characterised by extensive outcrops. The Purana rocks of the Nepal Himalayas could not be accurately correlated with any of the two facies on account of their great distance from the nearest out-crops, but very likely the map prepared by Burrard and Hayden represents the correct interpretation of things.

It is not unlikely that the Baxa limestone represents the Deoban limestone but until we have got some knowledge of the geology of the Nepal Himalayas, especially of their western portion, it will not be possible to say anything definitely about the relationship of the Nepal Purana rocks and the rocks with the Simla and the Darjeeling facies.

On account of the absence of any indisputable fossil remains the Krol beds have been referred to the Algonkian system. Mr. Oldham correlated the Blaini beds with the Talchirs but this opinion was controverted by Sir Thomas Holland (9). In a paper read before the fifth Session of the Indian Science Congress under the joint-authorship of Vredenburg and Das-Gupta (22) reference was made to the discovery of *Chonetes* in Krol beds, but this opinion was not accepted by Sir Henry Hayden who thought that the bed from which the fossil had been obtained was Tertiary as previously mapped by Medlicott (5). It is unfortunate that in this criticism one important point was completely lost sight of, *viz.*, the difficulty of always distinguishing between the Krol and the Subathu beds. While describing the Krol beds Medlicott remarked (33):—

"Among all these beds, as we ascend, shaly clays are introduced, after having a light, but bright, pink, and sometimes a mottled green colour. These clay rocks occasionally give rise to a little confusion when they occur at the contact with the Sabathu group."

From this quotation it is not unlikely that there may be some error in Medlicott's map, and an observation of Sir Henry Hayden may be cited in support. According to Medlicott, the Shali limestone, in the neighbourhood of Simla, is a Krol limestone (13) and the country round about the Shali peak has been mapped as belonging to the Blaini-Krol series, and the other rocks

found in this area are the infra-Blaini slates and the crystalline metamorphics. But sometime ago Sir Henry Hayden himself found out the occurrence of nummulitic limestone in this area (5 and 6), thus pointing out that Medlicott's map required emendation.

CONCLUSION.

In this note an attempt has been made to bring together in a concise form all that is known about the Purana outcrops along the entire length of the Himalayas and to correlate them more definitely than what has hitherto been done. The results that have been arrived at are tabulated in the accompanying plate.

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DARJEELING FACIES

…N	AKA HILLS	DAPHLA HILLS	ABOR COUNTRY	MIJU RANGE	GENERAL SEQUENCE	
	...		.	..		PURANA
	..		.			
			Metamorphic Series (Dolomitic)		Baxa	
	Daling	Daling	Mica-Schist Series	Daling	Daling	

COMMENTATIONES ALGOLOGICAE

IV

COMPSOPOGON LIVIDUS, (HOOKER) DE TONI

BY

Paul Brühl, D.Sc. and Kalipada Biswas, M.A.

In our account of *Compsopogon coeruleus*, Montagne, as growing in Bengal (*see* Vol. V. of the Journal of the Department of Science, Calcutta University) we had occasion to mention that we had noticed a second species of Compsopogon growing in similar localities to those in which we had observed specimens of *Compsopogon coeruleus.* We have been able to secure, during the present season, sufficient material for a detailed study of this second species.

It was late in February, 1923, that we discovered some specimens of this second species in a pond situated in Mr. H. Bose's nursery, Gariahat Road, Baliganj, after the disappearance of *C. coeruleus*; they were found attached to the leaves of *Hydrilla verticillata* and entangled in a mass of *Pithophora polymorpha.* During the present season *Compsopogon coeruleus* grew much less luxuriously than in the preceding year, evidently owing to its being choked up by dense masses of *Trebonema bombacinum,* which occupied the edge of the pond. On the other hand, the second species, which is undoubtedly identical with *Compsopogon lividus,* (Hooker), was much more plentiful. It grows on the leaves of *Hydrilla verticillata* and other aquatic plants as well as on the culms of grasses and on decaying sticks floating in the water of the pond; sometimes it also grows directly on the mud at a slight depth, nearly always at a distance of one to several feet from the edge of the pond. It is commonly intimately mixed up with filaments of *Trebonema bombacinum* and of species of *Spirogyra* and *Ulothrix.*

As a rule, the colour of *Compsopogon lividus,* where it occurs in dense masses, is bluish black, particularly so where it is situated underneath other aquatic plants or when it grows on the mud under a stratum of one or two feet of water, whilst when it is more exposed

to the rays of the sun, the colour merges into a paler greyish blue; after dying the colour becomes greyish white. Younger filaments are often deep blue or they are suffused with pink.

The branches and especially the ultimate branchlets are rather irregularly disposed and somewhat more scattered than they are in *C. coeruleus.* They are either nearly straight or more commonly sinuous or inflexed and they stand at angles to their parent axis of 52° to more than a right angle, the usual angles lying between 74° and 85°. In the majority of cases the branches originate on one side only of the parent axis, as shown on plate I, fig. 2; it is only because the main branches are often more or less twisted that the branchlets arising from them appear at first sight to be disposed all round. Some of the branches of the second, third or even fourth order develop rind cells without further branching. Such rinded branches are, of course, considerably stouter than the unrinded ones and are often decidedly truncate at their apex. The branchlets which have not developed a cortex gradually thin out towards the tip; the corticated branches are commonly 50 to 60μ at their base and 20 to 25μ at their apex. As in *C. coeruleus*, the branches originate from the central cylinder and never from the rind cells. The development of the rind cells starts at the base and proceeds in an upward direction; in detail it is quite similar to that described by us in the case of *C. coeruleus.* The axial cells are disc-shaped and contracted at the joints; when held against the light, the uncorticated branches present a beaded appearance; the cells at and near the apex are 3-7μ long by 10-15μ in diameter, whilst those lower down are 3-12μ long and 21-30μ in diameter. The cell-walls of both axial and rind cells are 2-3μ thick.

The contents of the upper cells of the branches are densely granular and deep blue; lower down the chromophores are ovoid or spherical, and along the walls they are arranged in rows.

The central portion of the older stem and the main branches consist of cells with very thin walls (*see* fig. 22 on plate III). The cortex consists of small cells of various sizes and shapes.

The organs of reproduction are similar to those of *C. coeruleus.* The microsporangia occur either singly or they form hemispherical or oblong sori of two to twenty cells, which are normally spherical, but become more or less polyhedral by mutual pressure. The sori either take their origin from rind cells or from the cells of uncorticated

branchlets. The diameter of the sori varies, according to the number of microsporangia, between 15 and 80μ. The microsporangia, when spherical, are about 9μ in diameter, when more or less oblong in surface view, they are 9 × 6-9μ. Development and discharge of the microspores is similar to that described in *C. coeruleus*. The microspores are 6-9μ in diameter; they are pale blue; the nucleus is placed centrally and the chromophores are less densely crowded near the centre than near the periphery.

The macrospores are probably always formed at night; they are less abundantly produced than in *C. coeruleus* and they originate in the rind cells. They are spherical, about twice the size of the microspores, usually 12μ in diameter, and contain a central nucleus and ellipsoidal, closely packed chromophores.

Only in one case was the commencement of the germination of a macrospore observed.

Compsopogon lividus has been observed by us growing only in stagnant pools. *Sir David Prain*, in No. 2, Vol. III of the Records of the Botanical Survey of India, reports the species from canal banks near Calcutta Salt Lakes and the banks of the Hughli. The species is found during the months of February to April; it appears to grow most luxuriantly between the middle of February and the middle of March.

The following is a description of the species:—

Compsopogon lividus, (Hooker) De Toni—frondibus caespitosis, 10-30 cm. longis, virgato-ramosis, saepe in massas densas coeruleo-nigrescentes intricatis; ramis ramulisque haud dense aggregatis, saepissime unilateraliter et plus minusqve irregulariter dispositis, angulos 52°-93° saepissime 71°-85° cum axi efficientibus coeruleo-nigrescentibus vel cinereo-caeruleis, ultimis saepe purpurascentibus, crassioribus saepe apice truncatis, ultimis saepius apicem versus attenuatis; cellulis axilibus disccoideis, ad genicula manifeste constrictis, corticalibus multo minoribus, configuratione variis, chromatophoris sphaericis vel ellipsoideis.

COMMENTATIONES PHYTOMORPHOLOGICAE ET PHYTOPHYSIOLOGICAE

IV.

EICHHORNIA STUDIES

III.

ON THE PRODUCTION OF RIPE SEEDS BY ARTIFICIAL POLLINATION OF EICHHORNIA SPECIOSA.

BY

PAUL BRÜHL, D.SC., AND JATISH SEN GUPTA, M.SC., UNIVERSITY RESEARCH SCHOLAR.

A search for ripe fruits and seeds of *Eichhornia speciosa*, the Water Hyacinth, in and around Calcutta and elsewhere, continued for several years, has up to the present proved abortive. The statement has been made that ripe seeds have been gathered in the District of Mymensingh, but the correctness of the statement has not been sufficiently substantiated to be above all reasonable doubt. In this connection we may refer to an interesting paper by the well-known naturalist FRITZ MÜLLER giving details of his observations and experiments made by him more than forty years ago at Blumenau in the Brazilian province of Santa Catharina (*see* Kosmos, Vol. XIII, pp. 297-300, 1883, and Gesammelte Schriften von Fritz Müller, edited by Alfred Möller, Vol. I, Part 2, pp. 968-981). A single specimen of the *Eichhornia speciosa* had

been introduced about the year 1863 into Blumenau, and in 1883 the descendants of that single plant were covering ponds and ditches and were forming floating meadows along the banks of the river Itajahy. FRITZ MÜLLER searched unsuccessfully for ripe fruits and seeds and arrived at the conclusion that the observed sterility was due to all the Blumenau plants having been derived from a single mesostylous specimen and that, as in a number of other cases, such plants could only propagate themselves vegetatively. Further observations, however, led to the discovery of ripe seeds as well as to macrostylous specimens and other specimens with differently coloured flowers, from which it followed that the ovules of mesostylous flowers could be fertilised by their own pollen or by the pollen derived from similar flowers. This was verified by experiments with artificial pollination.

FRITZ MÜLLER in his paper refers also to the observed fact that in many cases the pollen grains of heterostylous flowers are larger in the anthers of the longer stamens than those of the shorter ones. He had observed that in fruits which had matured in consequence of pollination of the stigma with pollen taken from the shorter stamens, the ovules situated near the base of the ovary had atrophied; there were, however, exceptions to the rule suggested by the result just mentioned.

Another experience of FRITZ MÜLLER is of considerable interest in connection with our subject. We therefore give here a translation of a passage in the publication referred to. "Of the seeds obtained as the result of last year's experiments I sent some to a German botanist, who wished to study the germination of the seeds; at the same time I sowed some seeds of the same gathering as well as some fresh ones in water. There they lay for three quarters of a year, after which I threw them away. I naturally expected to receive news from Germany that the

seeds sent by me had proved to be worthless, and I was consequently highly astonished when I heard that the seeds had germinated beautifully. As later on I discovered that older seeds germinated quite well, it appeared to me most probable that preliminary desiccation of the seeds might be a necessary condition of successful germination. Therefore, on the 15th of February I placed freshly harvested seeds of a mesostylous specimen of Eichhornia in a glass filled with water, whilst other seeds of the same crop I preserved in the dry state. On the 15th of the following March the seeds sown a month before appeared to have undergone no change. The seeds kept dry were now sown in water. On the 13th of April it was found that many of the seeds of the second lot had germinated, whilst none of the seeds of the first lot had done so. The latter were now taken out of the water and kept dry till the 22nd of April, when they were thrown again into a glass of water." On the 7th of May many of these seeds had germinated. These observations suggest that seeds which have got mixed up with mud which either dried up or was carried away adhering to the feet of aquatic birds are likely to germinate, sometimes in distant pools of water.

According to our observations the Indian specimens of *Eichhornia speciosa* are all of them mesostylous, that is to say, the stigma is situated at a level between that of the anthers of the three longer and that of the anthers of the three shorter stamens. The filaments of the longer stamens were found to be 21 to 25 millimeters, those of the shorter ones 6-10 millimeters long; the anthers of both sets are about 2 mm. long and 1 mm. thick; the style is 24 to 26 mm. in length; the anatropous ovules are approximately 500 μ long and 225 μ broad. The stigma is three-lobed, and the terminal area of the lobes is covered with hairs, which may or may not end in

glandular swellings. The style consists of three connate branches each of which is traversed by a central longitudinal canal. The filaments are beset with gland-tipped hairs.

The fruit is a trilocular ovoid-oblong capsule terminated by the dried-up style and enveloped by the marcescent corolla tube; it is either straight or curved and finally opens by three longitudinal slits. The numerous seeds are cylindrical, shortly attenuated at the base, truncate at the apex, which is formed by a central flat, nearly black area surrounded by the upper ends of the 11 to 13 lateral sharp and minutely undulated ribs, the spaces between which are marked with numerous transverse fine parallel lines; the colour of the testa, except the terminal area, is light-brown. The embryo is central, elongated, nearly of the same length as the seeds and surrounded by a mealy endosperm.

The first question to be decided was whether the pollen of the Water Hyacinth was capable of performing its proper function. As a first step towards a solution of this problem a number of culture experiments were made, the culture media used being 40, 20, 10, 5 and 2 per cent. solutions of cane-sugar and of glucose and 5, 2·5, 1·5, and 1 per cent. solutions of gelatine in distilled water. The 40, 20 and 10 per cent. solutions of sucrose and glucose proved ineffective, and the 5 per cent. solutions were moderately effective, and all pollen grains germinated in the 2 per cent. solution, although the solution of sucrose was undoubtedly the most effective. Of the solutions of gelatine the 1 per cent. solution produced the best results, but these were far inferior to those produced by the 2 per cent. solution of cane-sugar. The pollen grains germinate also freely in distilled water, but even here the 2 per cent. sugar solution is more effective.

It has often been observed that the pollen grains of shorter stamens are smaller than these of the longer stamens. The pollen grains of *Eichhornia speciosa* are ovoid; measurements showed that those of the longer stamens were 72 to 100 by 58 to 80 μ, thoseof the shorter ones 60 to 80 by 47 to 78 μ in length and breadth, so that although some of the pollen grains of the longer stamens are larger than the largest grains found in the shorter stamens, and some of the latter are smaller than the smallest of the longer stamens, pollen grains of the same size are found in both the longer and the shorter stamens.

As a curiosity, it may be mentioned that two flowers were met with which had seven instead of six stamens; in one of them the additional stamen had the same length as the longer stamens, whilst the other had a length intermediate between that of the longer and shorter stamens.

Our first attempts at artificial pollination were made between 10 A.M. and noon on the 11th, 12th, 13th and 14th of August last; they proved all of them unsuccessful. The next attempt was made at 7-30 A.M. on the 20th. The pollen was taken from the anthers of the longer stamens of other specimens; as a rule all the flowers of an inflorescence were pollinated. In those referred to three fruits were produced from one inflorescence and one from another. At 9-15 A.M. on the 8th of September all the flowers of five inflorescences were pollinated with pollen taken from the longer stamens of different plants. The results were as follows:—first inflorescence with four open flowers and six buds; second inflorescence with eleven flowers; third inflorescence with eight flowers; no result was produced in these three cases; the fourth inflorescence with ten flowers produced four ripe fruits,

the fifth with six flowers produced one ripe fruit. In this case it had been raining the whole of the preceding night and continued drizzling all day long. At 6-30 A.M. on the 9th of September the buds of three inflorescences were pollinated, but only one inflorescence produced one fruit; on the other hand of four inflorescences pollinated at 8-15 A.M. one with nine open flowers produced three fruits, one of five flowers produced five fruits, one of eight flowers gave rise to five fruits, and one of ten flowers produced also five fruits.

On the 10th of September at 8 A.M. seven inflorescences were pollinated with the pollen taken from anthers not yet dehisced: the number of flowers in each inflorescence varied from seven to ten; three produced no fruit, one of seven flowers gave rise to six fruits. It may be noted that there was a heavy shower of rain on that day lasting from 9 to 11 A.M. On the 11th of September four inflorescences were pollinated with pollen from the long stamens of the same flowers, one inflorescence of six and another of seven flowers produced six fruits each, one of seven flowers produced no fruit and another gave rise to two ripe fruits. At 7-45 A.M. on the first of October one inflorescence of nine flowers was pollinated with the pollen from the anthers of the short stamens of the same flowers; result: one fruit; another inflorescence of six flowers was pollinated with the pollen from the short stamens of another plant; result: three fruits. On the 7th October between 7-45 and 8 A.M. the seven flowers of one inflorescence and the eight flowers of another were pollinated with the pollen from the short stamens of the same flower; in the first case five fruits, in the second only one fruit was produced. On the 10th of October, at 8-45 A.M., the flowers of three inflorescences, two with six, the third with eight flowers, were pollinated with the pollen

from the short stamens of the same flowers; in all three cases each inflorescence produced four ripe fruits; the seven flowers of another inflorescence were pollinated with pollen from the short stamens of different flowers; result: four fruits. Two inflorescences with seven and eight flowers respectively when pollinated with the pollen from different flowers yielded the first one, the second two ripe fruits; the inferior yield may have been due to a constant drizzle lasting the whole of the night and day. The best result was obtained in an experiment made at 8 A.M. on the 8th of October, which was a bright day; an inflorescence consisting of seven flowers produced seven ripe fruits; the pollen was taken from the anthers of the long stamens of the same flowers. It may be noted that in the experiments with pollen taken from the anthers of the short stamens of the same flower the anthers of the long stamens had been removed.

It appears, therefore, that pollination experiments give better results if they are made on bright days; further that artificial pollination is best carried out between 7 and 9 o'clock in the morning and that it does not seem to make much difference whether the pollen is taken from the long or the short stamens of the same or of different flowers of the same or of different plants.

Our experiments show that it is not impossible that now and then ripe fruits and seeds of the Water Hyacinth may be produced in Bengal under natural conditions. That this does not occur more frequently may be due to the absence of certain insects which may be necessary to produce cross-fertilisation. If here and there ripe seeds should be produced, their distribution by aquatic birds would explain the appearance in isolated ponds and ditches and thereby the problem of the eradication of the Water Hyacinth would become even more complicated.

Further experiments undertaken by us have shown that the seeds obtained by us germinate freely, but especially well in wet mud. An account of these experiments will be published at a later date.

BOTANICAL LABORATORY,
UNIVERSITY COLLEGE OF SCIENCE,

The 15th December, 1925.

EXPLANATION OF FIGURES

1. Flower showing the relative position of the anthers and the stigma, $\times 2$.

2. Lower part of corolla slit open on one side and spread out, $\times 2$.

3. Anther, ventral aspect, $\times 19$.

4. Anther, dorsal aspect, $\times 19$.

5, 6. Glandular hairs of filament, $\times 52$.

7, 8. Two pollen tubes from artificial culture, $\times 80$.

9. Pollen tube, spirally twisted, from culture, $\times 120$.

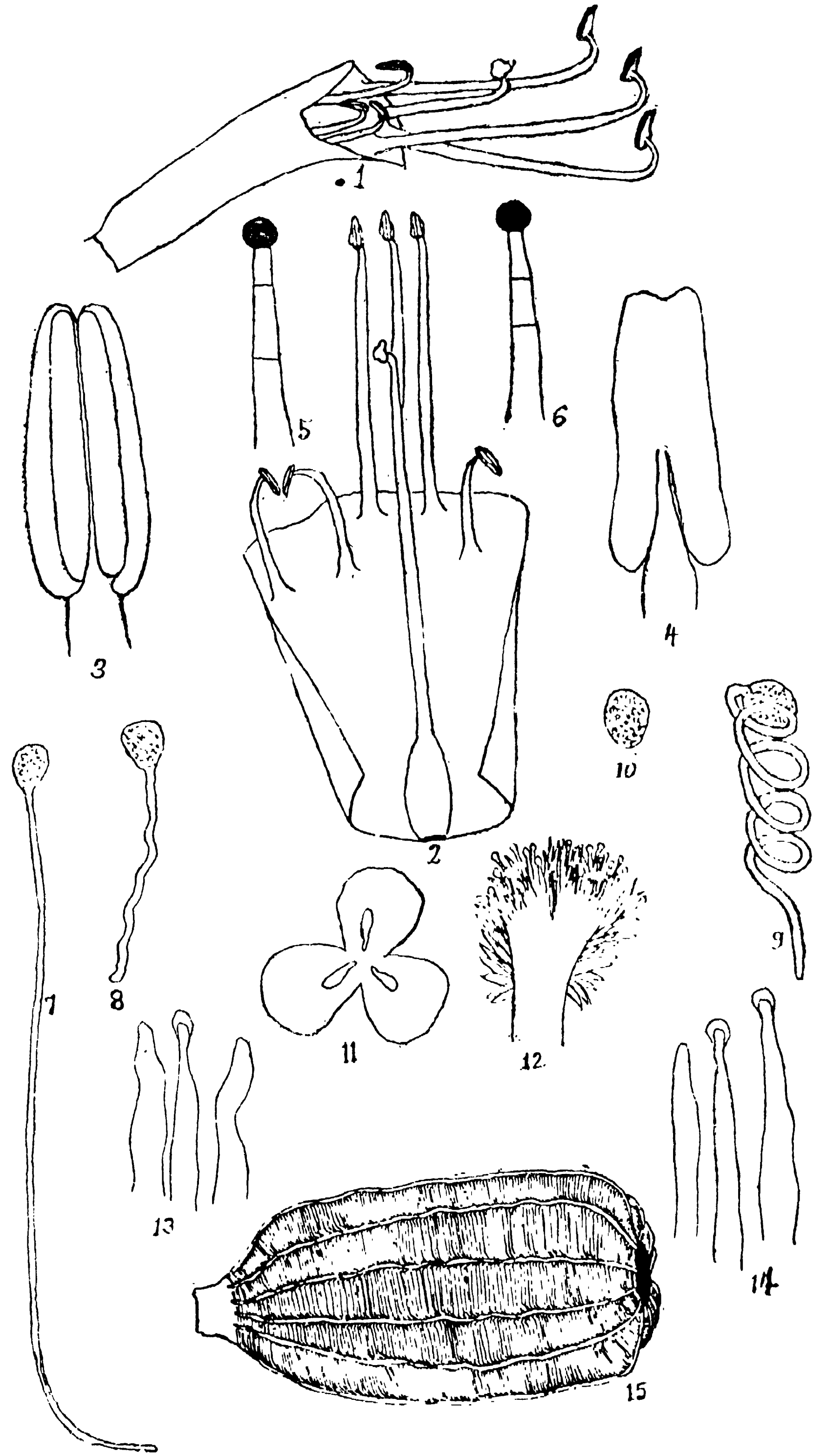
10. Pollen grain, $\times 80$.

11. Transverse section of the style showing the three canals, $\times 50$.

12. A stigmatic lobe, $\times 15$.

13, 14. Hairs from the stigma, $\times 58$.

15. Seed, $\times 40$.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PALÆONTOLOGICAL NOTES ON THE NUMMULITIC ROCKS OF CHERRA-PUNJI, KHASI HILLS, ASSAM.

(WITH PLATES).

BY

HEM CHANDRA DAS-GUPTA, M.A., F.G.S.

INTRODUCTION.

All students of Indian Geology are now aware of the existence of fossiliferous rocks in the Khasi hills and we are indebted to M. Deluc for the first mention of the occurrence of *Nummulites* in Assam.[1] A contributor, subscribing himself as F, was the second to give us some information dealing with the existence of fossils in these hills.[2] The area was subsequently visited by M'Clelland who recorded the occurrence of a large number of fossils in these hills including *Nummulites*.[3] At about the same time in a paper dealing with the geology of parts of Assam, Fisher pointed out the fossiliferous nature of the Khasi hill limestone.[4] The late Dr. Oldham visited the Khasi hills during 1851-52 and we are indebted to him for the first comprehensive account of the geology of these hills,[5] but, most unfortunately, the fossils that had been collected were lost during their carriage to England, though many of them were so characteristic as to lead him to suspect the presence of upper Cretaceous beds.[6] In their classical work dealing with the nummulitic rocks of India, d'Archiac and Haime described a few fossils occurring in the Khasi hills and these include *Nummulites scabra*, *N. obtusa*, *N. Lucasana*, *N. Beaumonti*, *N. exponens* and *N. spira*. Two important communications were then published by Medlicott dealing with the geology

[1] d' Arch and Haime : Monogr. d. Nummulites, p. 23.

[2] Glean. Sci. I, pp. 252-255, 1829.

[3] Journ. Asia. Soc. Beng., IV, p. 520, 1835.

[4] Journ. Asia. Soc. Beng., IX, pp. 808-843, 1840. Fisher's determination was not correct in all cases, as he mentions the occurrence of *Productа* among the fossils (*op. cit.*, p. 815).

[5] Mem. Geol. Surv. Ind., Vol. I, pp. 99-210, 1854.

[6] Q. J. G. S., Vol. XIX, pp. 524-526, 1863.

of Assam. In one [1] a short account of the geology of Assam was given and the other dealt with the geology of the Shillong plateau.[2] The fossils, collected by him, from the nummulitic series, were determined by Stoliczka and a short note contributed by him was embodied in the main report of Medlicott.[3] I had an opportunity of visiting these hills in 1917 in charge of a party of students from the Presidency College, Calcutta. A study of the nummulitic limestones collected has revealed the presence of some fossils not hitherto recorded from these beds and accordingly the present note has been drawn up.

Correlation of the Cherra-Punji Nummulitic Limestone.

In order to settle the position of the Cherra-Punji nummulitic beds with precision reference must be made to the species of *Nummulites* occurring in them. The species of *Nummulites* that have been hitherto observed as occurring in these beds by different persons are enumerated below :—

1. *Nummulites scabra* (d'Arch and Haime and Das-Gupta).
2. *N. obtusus* (d'Arch and Haime).
3. *N. Lucasana* (d'Arch and Haime and Stoliczka).
4. *N. Beaumonti* (d'Arch and Haime and Das-Gupta).
5. *N. perforata* (Oldham and Das-Gupta).
6. *N. Laevigatus* (Oldham).
7. *N. Lyelli* (Oldham and Das-Gupta).
8. *N. Lamarcki* (Stoliczka).
9. *N. Ramondi* (Stoliczka).
10. *N. Gizehensis* (Das-Gupta).
11. *Assilina granulosa* (Stoliczka).
12. *A. exponens* (d'Archiac and Haime).
13. *A. spira* (d'Archiac and Haime and Das-Gupta).

For a detailed account dealing with the distribution of *Nummulites* in India reference should be made to the late Prof. Vredenburg's paper [4] in which it has been shown that *N. scabra* = *N. Laevigatus* (*op. cit.*, p. 88), *N. obtusus* = *N. Gizehensis* (*op. cit.*, 85) and

[1] Mem. Geol. Surv. Ind., Vol. IV, pp. 387-442, 1865.

[2] Mem. Geo. Surv. Ind., Vol. VII, pp. 151-207, 1869.

[3] *Op. cit.*, p 167.

[4] Rec. Geol. Surv. Ind., Vol. XXXIV, pp. 79-95, 1906.

N. Lyelli = *N. Gizehensis* (*op. cit.*, p. 88). After the removal of these three species from the list, ten are left behind and they include seven of those enumerated by Prof. Vredenburg as occurring in the tertiary beds of Sind. The zonal distribution of these seven species is given below :—

	Laki	Kirthar.						
		Lower.	Middle.		Upper.			
		...	A	B	1	2	3	4
1. N. Laevigatus ...	...	+	+	+	...	...	...	..
2. N. Gizehensis ...	.	...	+	..	...	...	...	...
3. N. Beaumonti ...	...	..	...	+	...	...	...	..
4. N. perforatus .	..	+	+	+	+	.	...	...
5. A. exponens ..	+	+	+	+	...	...	...	...
6. A. spira ..	.	. .	...	+	+	..	..	...
7. A. granulosa ...	+	...	. .	...	. .	..	...	...

From the evidence of *Nummulites* it is reasonable to conclude that the beds containing the fossils represent the middle Kirthar facies and lean more towards the division B than towards A. The presence of *A. granulosa*, a very characteristic Laki form in the middle Kirthar beds is rather puzzling and either the vertical range of *A. granulosa* has to be very much extended or the anomaly is only an apparent one due to a wrong identification of the fossil. It may be further added that two of the species of the Khasi hill *Nummulites*, not included in the foregoing list, namely, *N. Lucasana* and *N. Ramondi*, have been found in the middle eocene beds.[1] Accordingly it is fairly certain that the table of the zonal distribution of *Nummulites* prepared for the Tertiary beds of Western India is also applicable in the case of the Khasi hills and the Cherra-punji nummulitic limestone is lutetian in age. With this determination of the stratigraphic position of the nummulitic limestone beds of Cherra-punji I shall now proceed to describe a few microscopic fossils obtained and hitherto unrecorded from these beds.

Geol. Mag., Dec. IV, Vol. VII, pp. 308-311, 1900.

Diatoms.

The algæ play a very important part among the fossils present in the limestone as revealed by the microscope. A few sections examined have shown the presence of diatoms. One of the sections containing these diatoms was treated with hydrochloric acid; the whole of the section was attacked and no silicious residue was left behind showing that, in course of fossilisation, the silicious skeleton was entirely replaced by calcium carbonate. A similar replacement of the silicious skeleton by carbonate of calcium has also been recorded by Cayeux.[1] These diatoms belong to three different genera. One of them is possibly *Eunotia,* Ehrenb. Sections showing both the rectangular Gürtelansicht and the bow-shaped Schalenansicht are present. The second genus that has been identified by me is *Navicula,* while the third genus represented is *Synedra* recognised chiefly by its elongated form.

Lithothamnion Grandis, n. sp. (Plates I and II).

The algæ are represented not only by the diatoms but also by the *Corallinaceae* as shown by *Lithothamnion* which apparently contributes an important part towards the formation of this limestone. It is an important constituent of the modern marine flora and, as far as known at present, is represented by a number of fossils beginning from the Jurassic time. These species are of some importance in correlation as almost all of them are confined to one particular system, one important exception being *L. racemus,* Aresch as, according to Rothpletz, it has been found to range from the miocene up to the present time.[2] All these species have been primarily described from the European countries and it is only in a very few cases that the genus has been recorded from the Asiatic land. As mentioned by Martin *Lithothamnion* is found in the cretaceous rocks of Curacao while calcareous algæ have been found in the cretaceous rocks of Borneo[3] and, according to the same author, schon seit der Kreidzeit spielen die Lithothamnien in den Tropen als Riffbilder eine wichtige Rolle.'[4] Sir Henry Hayden

[1] Mem. Soc. Geol. France Nord, IV, 2, p. 61.
[2] Zeitschr. d. deutsch., geol. Gesselsch, XLIII, p. 321, 1891.
[3] Centralbl. f. Min. Geol. u. Pal p. 161, 1901
[4] *op. cit.,* p. 165.

described *Lithothamnion* from the Kampa system of Tibet.[1] Dr. Brouwer has recently recorded the occurrence of *Lithothamnion* in the old Tertiary beds of East Indian archipelago.[2] The upper Tertiary beds of Japan,[3] New Guinea[4] and several places in the East-Indian archipelago have also yielded the remnants of this genus, the only species that has been identified in these beds being the well-known *L. ramoisissimum* Reus.[5] Brouwer has also recognised the genus in the Quaternary bed.[6] The fossil is but scantily known from India and a reference to this genus is to be found in the work of Adye who found plant remains, closely resembling the calcareous alga *Lithothamnion* from the miocene Leithekalk of the Vienna basin, in the neighbourhood of Bhogat in Navanagar[7] while the same genus was also met with in the sub-aerially consolidated Sohn Bana limestone,[8] and also in the Porebandor limestone.[9] Taking all these facts into consideration the discovery of *Lithothamnion* in the eocene rocks of Cherra-punji is extremely interesting. The Cherra-punji specimens seem to be nearly all broken resembling the 'abgebrochene Aststäcke' described by Schwager from the eocene beds of the Libyan desert.[10] The specimens are so completely broken that among a large number of individuals examined by me I came across only two cases in which the bushy nature of the plant has been preserved to a very small extent, while in the hand specimen I could see only the broken fragments. The fronds are usually fan-shaped, though in some cases they appear to be elongated and the size attained by one of them was about 5 mm. The sections show that the central part consists of a number of closely packed more or less isodiametric or parenchymatous cells which are followed by a number of concentric layers, each layer consisting of a number of rectangular cells. These

[1] Mem. Geol. Surv. Ind., Vol. XXXVI, p. 166, 1904. According to Prof. Douville this *Lithothamnion*—bearing limestone is Maestrichtian in age (Pal. Ind. N S, Vol. 5, Mem. 3, p. 13, 1901).

[2] Jahrb., v. h. Mijnw in Ned-o-Inde, 1917 Ie Ged., pp. 229, 230 *et seq.*

[3] Journ. Coll. Sci. Imp. Univ. Tokyo, Vol. XVII, Art. 6, pp. 17-19, 1902.

[4] Geol. Mag., p. 210, 1918.

[5] Brouwer: *op. cit.*, p. 243.

[6] *Op. cit.*, p. 255.

[7] Economic Geology of Navanagar State, p. 129.

[8] *Ibid*, p. 174.

[9] Q. J. G. S., Vol. LVI, p. 586, 1900.

[10] Zeitschr. d. deutsch. geol. Gesselsch, XLIII, p. 316, 189[illegible]

cells are fairly big in size and the walls are sufficiently thick. The length of the rectangular cells is 45μ—60μ and their breadth is 18μ—22μ. Tetraspores are unknown. Hitherto only three species of *Lithothamnion* have been recorded from the eocene beds. These are *L. Nummuliticum* Gümbel[1], *L. effusum* Gümbel[2] and *L. Aschersoni* Schwag.[3] According to Prof. Seward the size and the form of the genus *Lithothamnion* should be taken into consideration in determining the species.[4] None of the previously mentioned species has got cells which are as big as those found in the Khasi hills and the Khasi hill plant has been designated under a new specific name.

LITHOTHAMNION CHERRAPUNJIENSIS, n. sp. (PLATE III).

In one of the slides has been found the branch of a Lithothamnion which is quite different from the branches hitherto described. The branch is an elongated one measuring about 3 mm. without the central portion completely preserved. The concentric layers are very closely packed and the cells are extremely small. It is also quite unlike any of the known eocene species of the genus.

FORAMINIFERA.

The published lists of fossils obtained from the Khasi hill nummulitic beds show that though they include many of the different invertebrate sub-kingdoms, the largest number belongs to the foraminifera. My own experience also corroborates this and by examining a number of sections of the limestone with tqe help of a microscope I have come across certain genera (Foraminifera) which have not hitherto been recorded from these beds. The species of *Nummulites* occurring in these beds have been already described by d'Archiac and Haime[5] and I wish to record here the characters of a few foraminifera not previously recognised by any one as occurring in them.

[1] *Ibid*, p. 303, 1891.
[2] *Ibid*, p. 304.
[3] Palaeontographica, XXX, I, p. 117, 1883.
[4] Fossil Plants, Vol. I. p. 187.
[5] *op. cit.*, p. 363.

ALVEOLINA sp.

The sections of the limestone exhibit both the longitudinal and the transverse views of an *Alveolina*. According to d'Archiac and Haime three species of *Alveolina* are found in the nummulitic rocks of India and of them *A. ovoidea* d'Orb occurs in the Khasi hill nummulitic beds. [1] The species was also described by Carter [2] and from a comparison of my sections with the previously published descriptions and figures of *A. ovoidea*, it may be safely concluded that the fossil found by me is not identical with *A. ovoidea d'Orb.* The Khasi hill specimens may be compared with *A. melo*, *d'*Orb [3] and *A. Ovulum*, Stach, [4] but as no complete test is available, it is advisable not to risk any specific identification.

QUINQUELOCULINA sp.

The limestone also shows few sections of a *Miliola* both transverse and longitudinal. Though on account of the absence of the test nothing definite can be said about the characters of the species, I think that the transverse sections are quite clear indicating the generic characters of the fossils which are referable to *Quinqueloculina*.

TRILOCULINA sp.

Though a large number of the *Miliolas* is to be included within the genus *Quinqueloculina*, still there are a few which show by their characters that they belong to the genus *Triloculina*.

TEXTULARIA sp. 1.

The species is represented only by microscopic sections. The test is composed of six chambers, three on each side. The last two chambers are transversely elongated and the others are more or less rounded. The chambers on the two rows are fairly of the same size, the suture line is flexuous while the test is obtuse behind and truncate in front. Greatest width = ·18 mm. and length = ·2 mm.

[1] *Op. cit.*, p. 363.
[2] Journ. Bomb. Branch Asiat. Soc., Vol. V, p. 134, pl. 11, fig. 17, 1853.
[3] *Op. cit.*, p. 348.
[4] Palaeontographica, XXX, I, p. 95.

TEXTULARIA sp. 2.

This species, like the preceding one, is represented by sections. The test is composed of eight chambers, four on each side and the chambers on the two sides of the suture differ very markedly as regards size. The suture is flexuous, the larger chambers are transversely elongated while the smaller chambers are more or less rounded. Width at the base $= \cdot 12$ mm. and length $= \cdot 24$ mm.

ORTHOPHRAGMINA DISPANSA, SOW (PLATES IV AND V).

The species was created by Sowerby from materials obtained from Cutch and was named as *Lycophoris dispansa.* [1] Carter found out that it was a type of *Orbitoides* and recorded its occurrence also in Sind, and Arabia. [2] According to d'Archiac and Haime the fossil is also found in Baluchistan and the Punjab. [3] This fossil was also detected among the eocene fossils of the northern Alps [4] while Medlicott and Blanford have mentioned the occurrence of this fossil in the eocene beds of Surat [5] and in the Kirthar beds of Sind [6] which are lutetian in age and with which the Khasi hill beds show a great similarity as already mentioned. Dr. Verbeck detected the presence of this fossil in the tertiary rocks of Java [7] while the same author and Fennema in their important work dealing with the geology of Java and Madoura gave a detailed description of the fossil with a few beautiful figures. [8] It appears from a communication published by Newton and Holland dealing with the tertiary foraminifera of Borneo that *O. dispansa* was recorded from the eocene beds of Borneo as early as 1882, though, in the limestones observed by the authors themselves, this species was not found to be present. [9] A number of eocene foraminiferal limestones from Sinai was described by Chapman who detected *O. dispansa* in

[1] Trans. Geol. Soc. London, Ser. II, Vol. V, pt. III, p 327, pl. 24, figs, 16, -16 1840.

[2] Journ. Bomb. Br R.A.S., Vol V. p. 129, 1857.

[3] *Op. cit.*, p. 363.

[4] Abh. bayer, Akad. Wiss. math-physik Classe Bd. 8, p. 701, 1868.

[5] Geology of India, pt. I, p. 340, 1879.

[6] *Op. cit.*, p. 759.

[7] Naturk. tidjschr, v. Ned-Ind., Vol. LI., pp 120 124, 1892.

[8] Description geologique de Java et Madoura, pp. 1173 1174, 1896.

[9] Ann Mag. Nat. Hist., 7th ser., Vol. III, pp. 245-264, 1899.

some of them and according to whom *O. dilabida*, Schwager from the Libyan and the Mokattam series of Egypt is identical with *O. dispansa.* [1] A. Martelli has mentioned the occurrence of *O. dispansa* in the Parisian beds of the islets of Paros and Antiparos. [2] A few eocene limestones obtained from Egypt were described by Chapman who detected *O. dispansa* in them and found it occurring in the Baharia oasis, [3] while in the same year A. Martelli recorded the occurrence of this fossil in the eocene rocks of Spalato in Dalmatia and distinguished the forms A and B. [4] Later on, Prever found this fossil at Leonessa in the central Appennine chain. [5] *O. cf. dispansa* has been noted by Deprat among the eocene fossils of New-Caledonia. [6] This short sketch gives us an idea about the geographical distribution of *O. dispansa*, Sow and the occurrence of this fossil in the nummulitic rocks of the Khasi hills is not surprising in the least. The fossil is very minute in size and I succeeded in getting a section showing the characteristics of the fossil fairly well leaving no room to doubt its identification.

Diameter = 2·6 mm.

ORTHOPHRAGMINA RADIANS, D'ARCHIAC (PLATE VI).

This fossil was at first described as *Orbitolites radians* by d' Archiac. [7] It, however, underwent a revision at the hands of Gümbel who studied the internal structure of the test, found out its true nature and gave a full description of the species, *Orbitoides radians.* [8] He was followed by Schlumberger whose description of the species [9] agrees, in the main, with that of Gümbel. Two of the sections of the Khasi hill nummulitic limestone shows the presence of a species of *Orthophragmina* quite different from *O. dispansa* and, though only a very scanty material is available for study, I have no hesitation in identifying it as *O. radians.* I failed

Geol. Mag. Dec., IV, Vol. VII, pp. 308-310, 1900.
Boll. Soc. Geol. ital., Vol. XX, p. 118, 1901.
Geol. Mag. Dec. IV, Vol. IX, p. 112, 1902
Pal. ital, Vol. VIII, pp. 83-84, 1902.
Atti d. R. Accad di Torino XL, pp. 574-575, 1905.
Bull. Soc. Geol. France ser. 4, Vol. V, p. 505 1905.
Mem. de la soc. Geol, France ser. 2, Vol. III, p. 405. 1850.
Abh. d. k. bayer. Akad. d. Wissensch. Bd. X, pp. 707 709, 1870.
Bull. Soc. Geol. France ser. 4, Vol. IV, pp. 122-124, 1904.

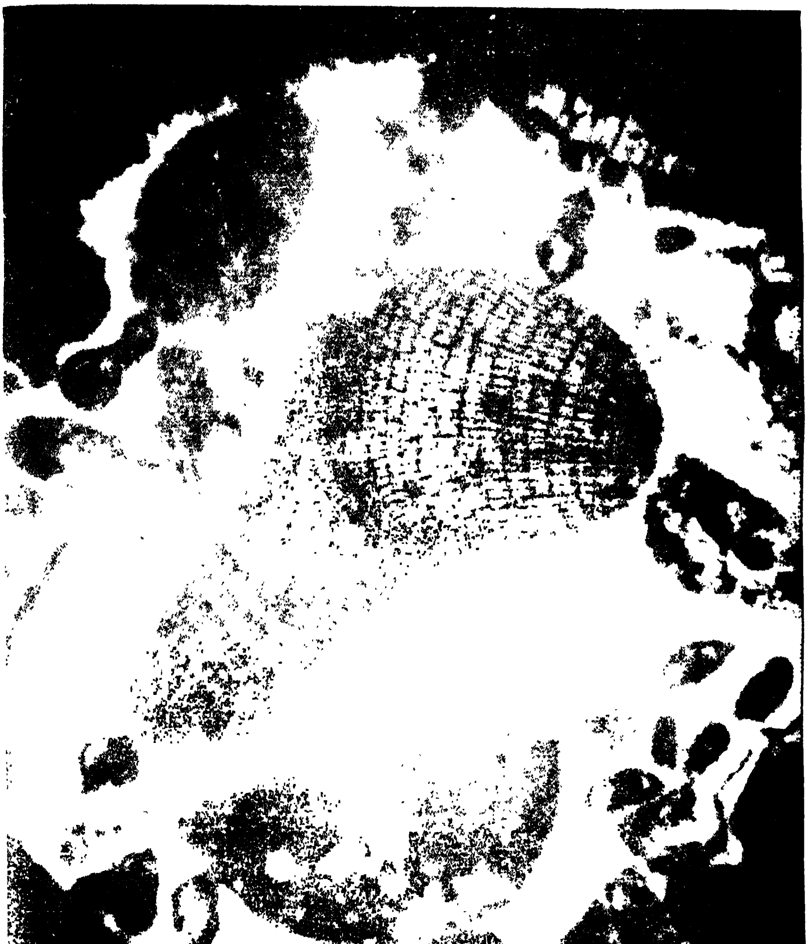
to find out any trace of the exterior of the test. This exterior is very characteristic, but the median chambers of the species are also peculiar in being very closely packed and the individual rows of these chambers have a marked zigzag arrangement 'durch ungemein häufiges Einsetzen neuer und durch das Auskeilen bestehender Cyclen.' Schlumberger also found this character to be a very constant one and he has described it thus :—

'A la suite, on voit deux ou trois cycles réguliers, circulaires, puis leurs parois extérieures se gondolent, s'arrêtent parfois brusquement sans faire un tour complet, d'autres viennent se superposer, il se forme de petits secteurs qui s'intercalent et, il en resulte un ensemble, souvent très confus, de loges de toutes dimensions.' It may be added that according to Schlumberger this species has been found at Mokkatam where, as it has already been mentioned, *O. dispansa* also occurs.

EXPLANATION OF PLATES.

Plate I—Lithothamnion grandis, n. sp.
,, II—Lithothamnion grandis, n. sp.
,, III—Lithothamnion cherrapunji-ensis, n. sp.
,, IV—Orthophragmina dispansa, Sow.
,, V—Orthophragmina dispansa, Sow.
,, VI—Orthophragmina radians, d'Archiac.

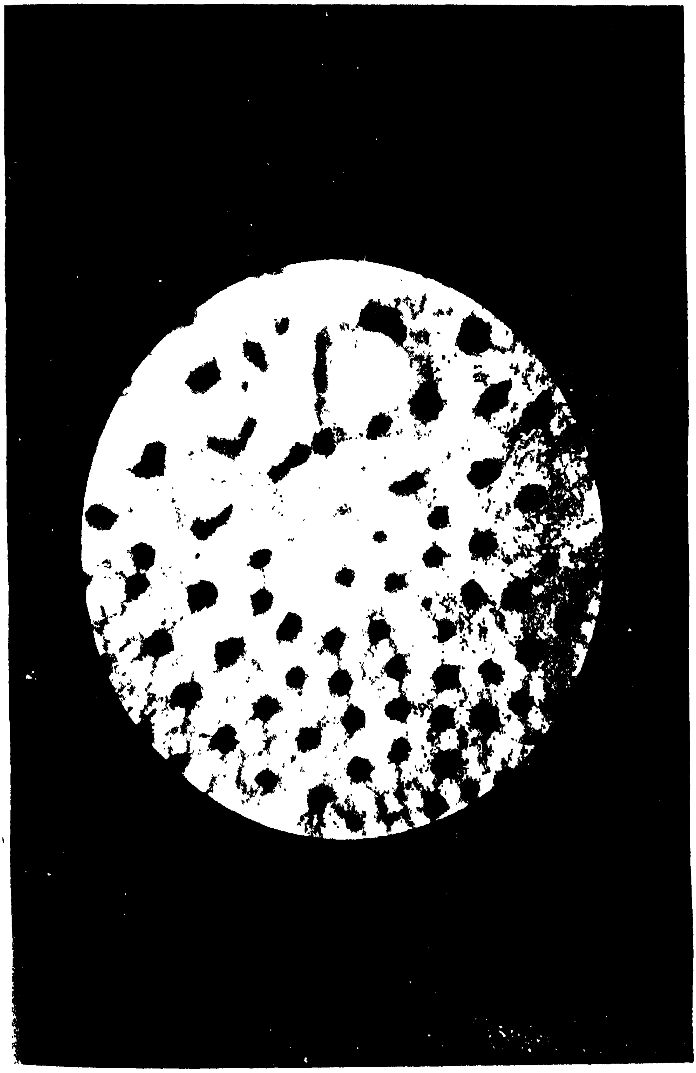
All the figures are magnified.



Lithothamnion grandis, n. sp

Lithothamnion grandis, n. sp.

Lithothamnion cherrapunjiensis, n. sp



Orthophragmina dispansa. Sow.

Orthophragmina dispansa Sow.

Orthophragmina radians. d'Archiac

Notes on Pentatrichomonas Canis auri N. SP., Found in caecal contents of an Indian Jackal (Canis aureus), its cultivation in vitro and its method of multiplication.

(With one plate illustrating the paper.)

By

G. C. CHATTERJEE, M.B., HARENDRANATH ROY, M.SC.,

AND

A. N. MITRA, B.SC., M.B.

Pentatrichomonas has up to now been found only in the human intestines and that only by a limited number of observers: Derrien and Aynaud, who describe it under the name of Hexamastix Ardin-Delteili having found it in Algeria, Chatterjee who discovered it in India, Haughwout and Deleon at Manilla, and Kofoid and Swezy in America. Most of the observers agree as to its property of pathogenesis to man, which Trichomonas does not possess. For this and for certain other reasons Kofoid and Swezy as well as Castallani have considered Pentatrichomonas a distinct genus. Fonseca adopted Chatterjee's generic name Pentatrichomonas, of which *Pentatrichomonas Ardin-Delteili* is a species found in man. For this reason, if not for any other, the discovery of Pentatrichomonas in a carnivore is of great importance.

MATERIALS FOR OBSERVATION.

On examination of the caecal contents of a jackal, accidentally killed, numerous trichomonads were found, which on further examination of stained films proved to belong to Pentatrichomonas. As Pentatrichomonas has never been found outside human beings, this organism was subjected to a further study by making several preparations from caecal contents as well as from materials pressed out from caecal crypts after washing the mucus membrane with normal saline. Cultures were also made in normal saline to which a little peptone was added, this proving to be a very good culture medium for the organism in comparison with any other culture medium.

Examination of living organism.

On examination of a hanging drop preparation of the caecal contents or of the culture the organisms were found to have a movement like that of an ordinary Trichomonas.

The organism remained confined to the bottom of the culture tube, this phenomenon being due more to geotropic action of which we got abundant proofs. If the capillary tubing in which culture is made is allowed to stand on the sealed end containing no air bubbles, the growth is confined to this lower end. If the upper open end be sealed and the position be reversed, allowing a bubble of air to remain at the bottom end, the growth remains also confined to this end.

Examination of stained films.

Though several specimens were stained by iron haematoxylin, after fixing in the moist state, most of our deductions were made from films stained by the modified Leishman stain, as by this differential stain all the organelles were brought out much more clearly than by iron haematoxylin, the fixation being moreover done much more quickly, a distinct advantage.

Smears from the contents of caecum.

Most of them appear like that shown in figure I of our plate to be adult forms, in which there is a massive nucleus and a number of basal granules agglomerated into a lump from which originate five anteriorly directed flagella arranged in one cluster. The sixth flagellum forms the border of the undulating membrane up to the posterior end where it becomes free. There is a chromatic line forming the base of the undulating membrane. Besides, there is an axostyle originating from the basal granules, passing through the nucleus and becoming free at the posterior end. It takes the chromatic stain without any difficulty and is often composed of a single fine chromatic line. A line corresponding to the parabasal is found in this Pentatrichomonas. (See Fig. 7.)

S EAR FROM PRESSED OUT CONTENTS OF CRYPTS.

In this several organisms in different developmental stages are found besides the adult ones. Some are in the plasmodial stage with a chroma c line lining a border. Some in which the marginal chromatic line has formed itself into a curve bounding the

undulating membrane without differentiation into flagella. In others again it has differentiated itself into an undulating membrane and a single flagellum which has not broken up into six flagella. No dividing forms, much less a somatella, was ever found.

CULTURE STAINED FILMS FROM CULTURE.

Besides the organisms found in the caecal contents, numerous very large organisms possessing all the characteristics of an adult Pentatrichomonas were found as well as numerous very minute forms possessing all the organelles of adult one. In no case any divisional form was ever seen, much less the Somatella form. As Pentatrichomonas has only been found in human beings (Chatterji, Raynaud Derrieu), this species is evidently a new one. The human one having been designated Pentatrichomonas bengalensis by Chatterji and P. Aidin-Delteili by Fonseca the present form is named by us Pentatrichomonas Canis auri.

CONCLUSION.

A new species of Pentatrichomonas has been found in the jackal. It has been cultivated in vitro. We have failed to observe its method of multiplication either by binary or by multiple fission.

The five free flagella in this species are not arranged in two groups as Kofoid and Swezy describe in P. Ardin-Delteili, but in a single bunch directed forward. In Pentatrichomonas the axostyle is composed of two linear structures, whereas in this Pentatrichomonas it is composed of a single linear structure.

For the reasons mentioned above it can be safely considered to be a species distinct from the one found in man and may therefore bear the specific name of Pentatrichomonas Canis auri.

DESCRIPTION OF PLATE.

The specimen was one taken from a week's culture of Pentatrichomonas. All figures are drawn with camera lucida and stained in modified Leishman stain. × 1800.

Figs. 1 to 8	represent	adult organisms showing 5 free flagella originating from a group of basal granules, the sixth flagellum is seen bordering the undulating membrane.
„ 9 & 10	„	rounded forms with numerous chromatic granules, Chr. g. are chromatic granules.

Figs. 11 to 13 represent the plasmodium stages.
,, 14 & 15 ,, the flagella are formed, but not differentiated.
,, 16 ,, the flagella differentiated.
,, 17 to 20 ,, minute organisms with 6 free flagella.

In fig. 7, n the nucleus.
a the axostyle.
p the parabasal.
u the undulating membrane.
Chr. b the chromatic base.
b the basal granules.
I to V the free flagella.
VI the bordering flagellum.

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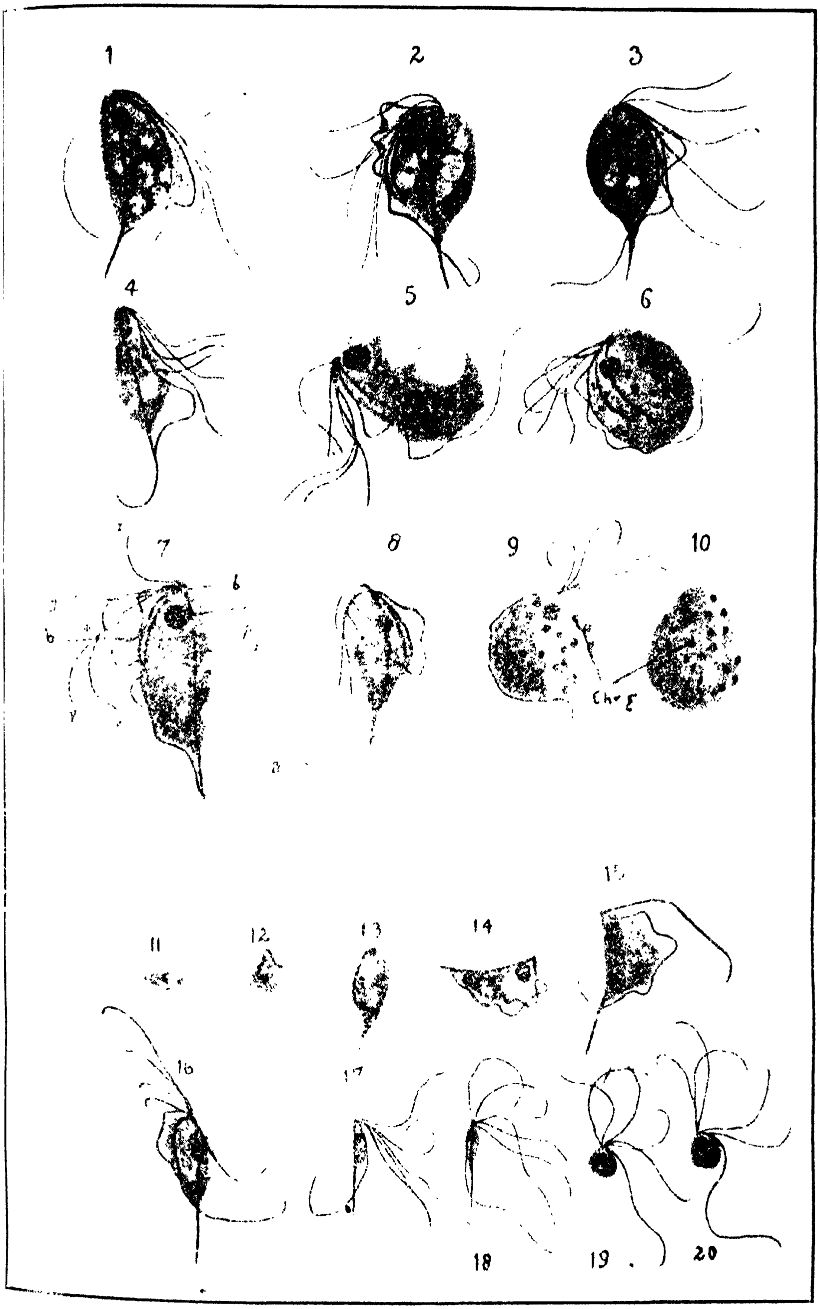


A Note on the Method of Multiplication of Trichomonad Flagellates of Different Species in Artificial Culture.

BY

G. C. CHATTERJEE.

Having observed that the method of multiplication of Trichomonad Flagellates of different species differs from that hitherto described, I have thought it advisable to publish my observations on it.

Materials for observation :

1. *Trichomonas* from intestine of Gecko.
2. ,, ,, ,, ,, Russel's Viper.
3. ,, ,, ,, from frog.
4. ,, ,, ,, ,, house-lizard.
5. *Pentatrichomonas* from intestine of man.

As the methods of multiplication of all the species observed by me agree in all material points among themselves, there is no necessity for me to describe each of them separately.

Method of observation :

The trichomonas along with intestinal contents were placed in a capillary tube containing normal saline, to which a small quantity of haemoglobinised human blood was added. As in all these species growth took place easily and could be subcultured indefinitely (except in case of the human one, which lived for 20 days only), abundant material was obtained for observation. In making stained films, the iron-haematoxylin method, after wet fixation, was used; but the modified Leishman stain, after dry fixing, was found preferable, as by adopting this method not only greater rapidity of work was secured, but also differential staining of different organelles was obtained without loss of their character. This gave an advantage which could not be had with iron-haematoxylin.

Characters of the Growth :

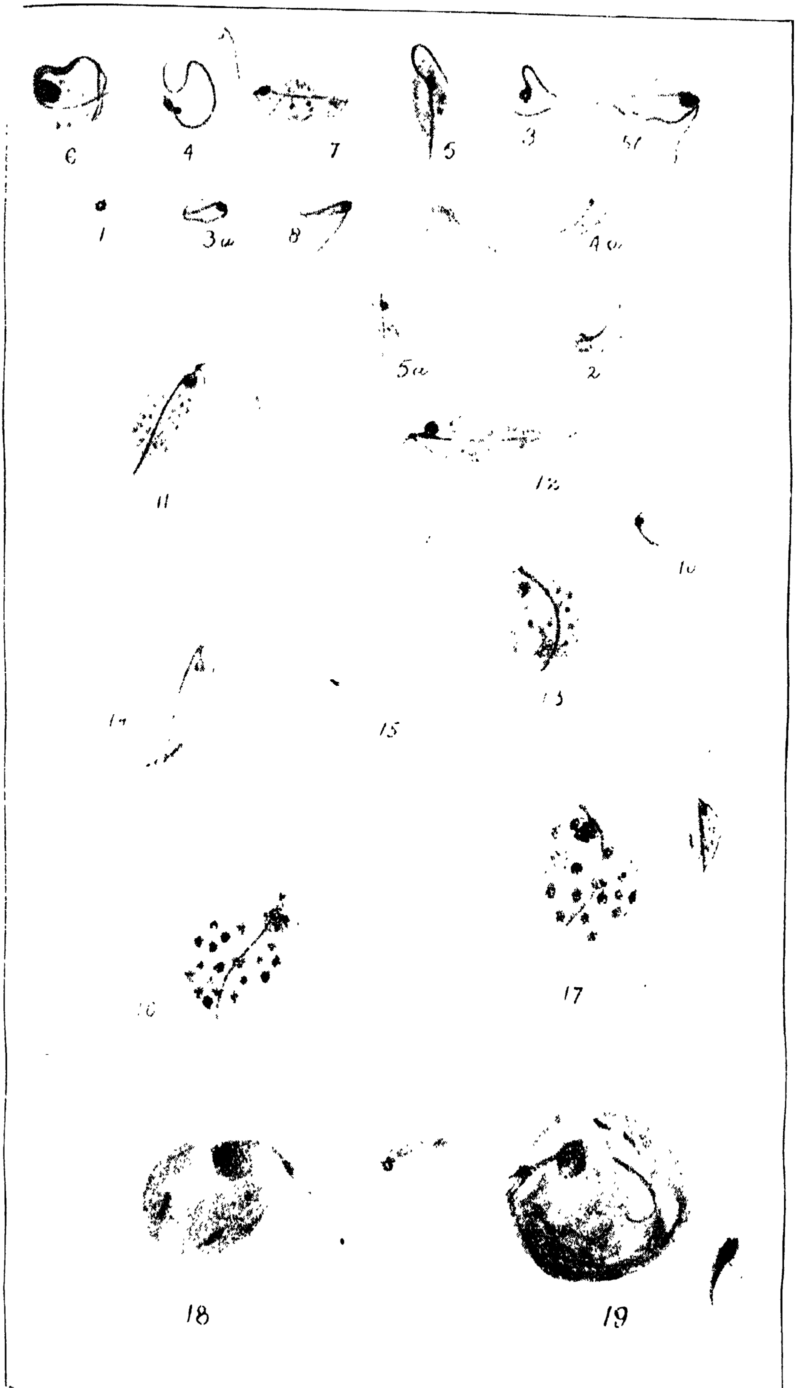
As a rule, multiplication took place at the bottom of the tube. It was found that it had nothing to do with the organisms being anaerobic as was suggested by CHATTON, as when a droplet of air was left at the bottom of the tube, growth took place as abundantly as when there was no air. Besides, it has got nothing to do with the presence of bacteria (CHATTON). Another point noticed is the cyclic growth : at times there is a meagre growth, at another time the growth was intensive. This again was not found to have any connection with the composition of the culture medium. This intensive growth is always associated with the presence of a large number of giant-sized organisms mixed with numerous very minute forms in various stages of development.

Stained films:

An idea of the morphological characters of the organisms found in the culture will be best obtained, if I describe them under the following heads :—

1. *Fully developed form.*—(Plate Figs. 11 and 12), as found in intestinal contents of animals; it has a pear-shaped elongated body in the anterior end is the nucleus which does not present any special character ; as a rule, it is massive in structure. In front of it basal granules arise in definite number. From these arise the anterior free flagella, three in number in *Trichomonas* and five in *Pentatrichomonas*, one attached flagellum forming the border of the undulating membrane and a fine chromatic line (parabasal), not always present, along the border, ending near the posterior end of the organism and forming a short curve. An axostyle is found originating from the basal granules and ending in the posterior end; it is a brightly staining chromatic line ; sometimes there are two in number (*Reuling* found four in *Trichomonas vaginalis*), never a hollow tube containing chromatic dots (*Kofoid* and *Swezy*); the cytoplasm of the organism is often full of chromatic dots which have nothing to do with nuclear division. These are the mitochondria, whose nature has not as yet been explained. They do not come out by the iron-haemotoxylin stain.

2. *Giant-sized organism.*—Giant-sized organisms, length 32μ, breadth 25μ, having all the organelles of the typical organism except the undulating membrane (see Plate Figs. 16 and 17). Mitochondria



are found in large numbers. A single nucleus is found, but it shows no evidence of multiplication. It is, as a rule, deficient in chromatin.

3. *Trichomastix form*—(Plate Fig. 14.) Big organisms taking intense staining as a rule, free from mitochondria and showing a single nucleus, four free flagella, one being a trailing one, and a well-stained axostyle, which is curved and not a straight rod.

4. *Small adult forms.*—(Plate Figs. 8, 9, 10 and 15 and Text Figs. 14 and 15). Having all the characteristics of the adults with a straight axostyle protruding well out of the posterior end and possessing all the organelles of adult ones. There are three anterior free flagella and a fully developed undulating membrane. Size varying from 3 to 4μ in length, 1·5μ in breadth.

5. *Developmental forms*—Numerous types of developmental forms are found in intense growths. (*a*) Plasmodium forms showing a brightly stained nucleus (Plate Fig. 1, 3*a*, 4*a* and text figures Nos. 1 to 8 and 10 to 12), a chromatic line originating from the nucleus without the intervention of basal granules forming the marginal border; another chromatic line, axile in position (axostyle) originating from the nucleus [Plate Fig. 6].

6. *Other developmental stages.*—The marginal line forms a loop—a stage in the formation of the undulating membrane (Plate Figs. 2 and 4*a*).

The next stage.—In this the marginal chromatic line has differentiated into three flagella and an attached flagellum.

Conjugating forms (*3*).—Two specimens were found, as depicted in Figs. 18 and 19, in which one of the fiagella of the giant organism was found continuous with the flagellum of a minute organism.

Discussion:

In hanging drop specimens of the bottom portions of the culture some of the giant-sized organisms were found to be very granular. The giant ones being very active, it it very difficult to observe them for any length of time; but in many of them are found small plasmodium-like organisms attached to the pointed free end of the axostyle. They give the impression of minute gemmules (Plasmodium forms seen in Fig. 1) coming out of the giant organisms. This seems to be the ordinary method of multiplication of Trichomonas organisms in vitro; and this impression is confirmed by the appearance seen in stained films made of material from the hanging drop, where this

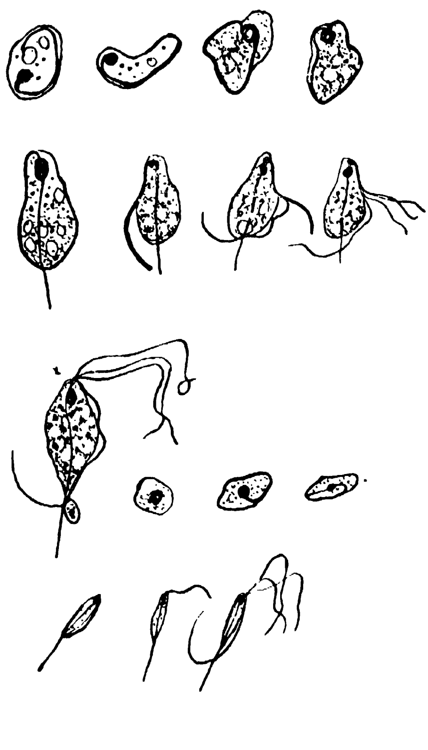
phenomenon was observed. Numerous developmental forms found at different stages of development also support this view. Cultures from different types of *Trichomonas*, of which I have six, carried on for nearly 6 years, in each of which I found the same phenomenon as depicted in this paper, leave no doubt in my mind that this is the ordinary method of multiplication. If multiplication of a *Trichomonas* takes place only by binary fission or by somatella (having component parts, each possessing at the time of division, most of the organelles of a fully developed organism, namely a nucleus, an axostyle, three free and one attached flagellum as observed and described by Kofoid and Sweezey, Reuling and Doflein and other observers), it is difficult to explain the presence in my specimens of numerous plasmodia and other similar forms possessing none of those organelles of a Trichomonad flagellate.

A word of explanation is necessary regarding what takes place under conditions prevailing in the intestine. Examination of stained films made directly from the intestine shows only the adult forms—no giant forms or minute forms or developmental forms are seen. In one case only—in a lizard—a few developmental forms were seen in specimens made directly from intestinal contents. When a culture is made of Trichomonas from intestinal contents, after two or three days multiplication takes place, but at first it goes on very slowly. In stained films from it only fully developed, but no developmental forms are seen. Suddenly intensive growth takes place and that after the fourth day or so, and with this the giant ones mixed with minute forms appear. This to me suggests a tentative theory, namely that somewhere in the intestinal crypts multiplication by gemmules separating from giant organisms goes on, on lines seen in culture in vitro, possibly by gametogenesis; these come out from the crypts and form the adult ones, and these are the ones which we find in intestinal contents, the developmental forms escaping detection.

Trichomastix serpentis Dobell is possibly a developmental form of a *Trichomonas.*

Summary:

Multiplication takes place in artificial culture by gemmules coming out from actively moving giant organisms.



Descriptions of plates.

Films were made by modified Leishman's stain and figures were drawn with camera lucida, with $\frac{1}{12}$ th oil immersion.

Fig. 1.—a plasmodium form—a nucleus is only seen.

Fig. 2.—a plasmodium form : in this a chromatic line originating from the nucleus forming a loop, which becomes differentiated into the undulating membrane and free flagella.

Fig. 3.—a plasmodium form—the chromatic line is still intra-cytoplasmic.

Fig. 4.—a plasmodium form—from the anterior end of the nucleus is seen the chromatic line which forms one boundary of the cell from the posterior and is seen originating the axostyle.

Fig. 5.—Same as 3.

Fig. 5*a*.—Same as 3 and 4, except a little more developed and a few mitochondria are seen.

Fig. 5*b*.—Do. do. do.

Fig. 5*c*.—The chromatic line is differentiated into the undulating membrane and a single thick flagellum which becomes differentiated into three flagella.

Fig. 6.—Same as Fig. 4, except that it contains a few mitochondria.

Fig. 7.—More developed stage than Fig. 5*b*.

Figs. 8, 9, 10 and 15. Small adult forms with all the organelles.

Figs. 11. A fully developed adult form with numerous mitochondria.

Figs. 13 and 14 A Trichomastix form with curved axostyle.

Figs. 16 and 17 A Trichomastix form with numerous brightly stained mitochondria.

Fig. 18 A conjugating form one of the flagella of the giant organisms is seen continuous with that of a small organism.

Fig. 19 Two minute organisms are seen attached to a giant one.

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CALCUTTA,
The 16th April, 1925.

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Notes on the Occurrence of Ovaries in the Worker of *Myrmicaria brunnea* Saunders.

(Read before the Thirteenth Session of the Indian Science, Congress, held at Bombay, 1926.)

BY

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It is known that in the winged female of ants the reproductive system in general consists of a pair of ovaries having a number of ovarioles opening into oviducts. The pair of oviducts unite to form the uterus with which the receptaculum seminis is connected by a narrow duct. The uterus opens behind into the vagina, on the dorsal surface of which the copulatory pouch is situated.

The ovaries in the worker, while conforming to the same plan of organisation, are more simple and characterised by the possession of a fewer number of ovarioles, the receptaculum seminis being present or absent. The number of ovarioles in the worker of several European and American species was determined by Alderz, Bickford and Holliday and was found varying in different species or even among individuals of the same species.[1] Sometimes the ovarioles were found wanting, and in a limited number of specimens examined by Holliday the ovaries were absent.[2] But Wheeler doubts the complete disappearance of ovaries in the worker of any of the Formicidae. As

[1] Wheeler, Ants, 1910, p. 39-40.

[2] Holliday. A Study of Some Ergatogynic Ants. Zool. Jahrb. Abt. Syst., Vol. XIX. pp. 293-328, 1904.

in a few cases the workers are supposed by myrmecologists to lay eggs capable of development, the knowledge of the condition of ovaries in the worker becomes of especial interest. Again, the reproductive power of the worker is held by Alderz to be dependent on the presence of a receptaculum seminis irrespective of the reduced number of ovarioles, whereas, according to Holliday, the condition of the ovaries and not the presence of a receptaculum seminis determines the functioning power of the ovaries.

However, as the occurrence of ovaries in the worker of Indian species is not known, attempt is here made to investigate whether ovaries are present in all of the workers of some species common in Calcutta and if so, in what state they exist.

For dissection *Myrmicaria brunnea* was chosen on account of its comparatively large size and of being found throughout the year in one and the same nest. Further, the presence of winged forms of females in the same colony simplified the problem of the role played by their workers in the production of eggs. A small number of workers of *M. brunnea* from the same colony was examined from time to time throughout the year. Only in three or four out of nearly a hundred specimens examined the existence of ovaries was detected. Of these, one examined in June revealed the presence of ovaries of comparatively large size, while others at the same time showed none. Again in September, in a single specimen, ovaries of smaller size were found. It is also quite possible that in some the ovaries escaped attention due to their minute size. None of the workers revealed the presence of a receptaculum seminis. A description of the ovaries found is given below.

The ovaries of the worker examined in June consist of a pair of ovarioles together with a pair of well developed oviducts, the length of the oviducts approximately being 0·8 mm. (Fig. I). The oviducts were unsymmetrical, one side being spherical (Fig. I, *b*), while the other is more or less ellipsoidal in shape and twice as long as wide. By the union of the oviducts at their posterior ends a common passage was formed (Fig. I, *c*). A single ovariole opened into the apex of each oviduct (Fig. I, *a*). The ovariole was one and a half times longer than the oviduct, of uniform diameter, but was tapering at its extremity, the maximum width being ·045 mm. The tubule and the oviduct on both sides contained immature eggs, and not a single egg was found in the mature condition.

The ovaries in the worker examined in September were about three times smaller than those of the previous one (Fig. II). The oviducts were very small in size and oval in shape (Fig. II, *b*). The tubule was proportionately large, being three times the length of the oviduct (Fig. II, *a*). The tubule was narrow, long and straight, its width being about ·03 mm. The transition from the oviduct to the tubule was not very well marked, the one gradually passing into the other. At the junction of the ovariole with the oviduct, a tubular projection was seen, probably only representing the accidentally cut end of another tubule. In the ovaries mature eggs were not found.

It is evident from the above that in the majority of the workers ovaries are absent, the queen being the functional female.

In this connection a few workers of *Camponotus compressus*, *Sima rufonigra* and *Diacamma vagans* were also examined and no ovaries were found in them.

It is interesting to note that, though the workers of *D. vagans* are supposed to lay eggs, its female winged form being unknown, no eggs or ovaries could be found in specimens so far examined. But the occurrence of ovaries in the worker of *M. brunnea* points to the possible existence of such in a few cases and these demand further investigation.

EXPLANATION OF FIGURES.

Fig. I represents the ovaries of the worker examined in September. Eggs are shown only on the left side.

Fig. II represents the ovaries of the worker examined in June.

a—Ovariole.

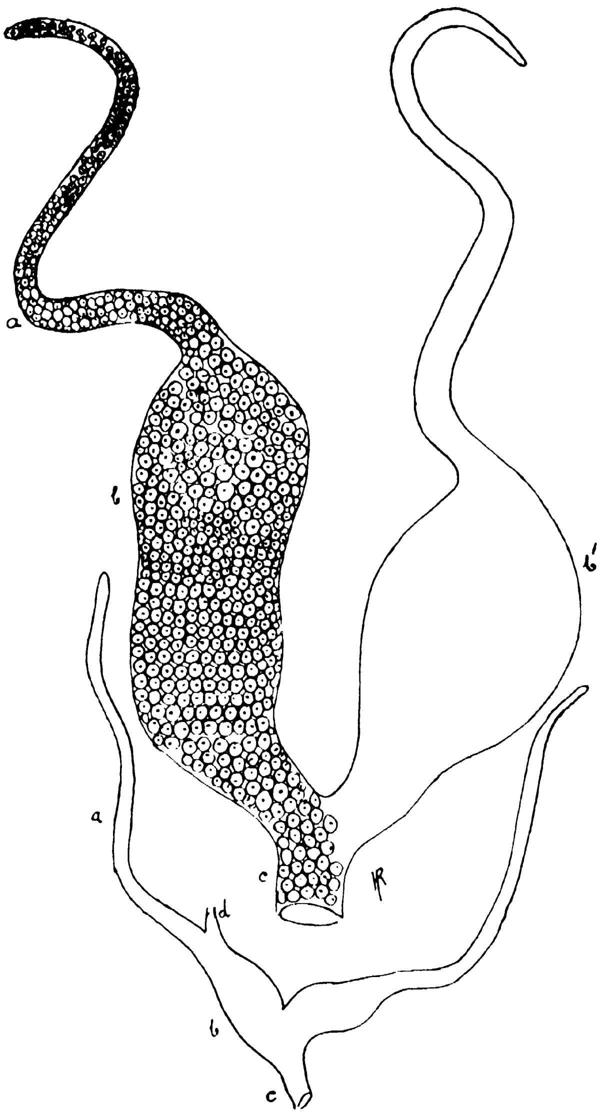
b—Oviduct.

c—Common duct.

d—Portion of a Tubule.

FIG. I.

FIG. II.



OVARIES IN THE WORKER OF MYRMICARIA FERUMCA. × 120.

Flora of the Salt-Lakes.

INTRODUCTION.

Excursions to the Salt-lakes in the 24-Parganas, Lower Bengal, made during the year 1921 and 1922, suggested to me the idea of writing a monograph on the algal flora of the Indian Salt-lakes. With this in view I made, in January, 1924, a small collection of algae growing in the Salt-lakes at Ennur near Madras. In March 1924, the late Dr. N. Annandale, the Director of the Zoological Survey of India, was kind enough to ask me to accompany him to the Chilka Lake, where I stopped with him for a week on Berkuda Island. This gave me an opportunity of studying the vegetation of the lake, and with his help I was able to make a collection of algae growing in the lake as well as on the islands of the lake. Moreover, during the years 1922 and 1923 Dr. Annandale sent material to Dr. P. Brühl, the University Professor of Botany, under whose guidance I am doing research work. This collection is now being worked out and the result of the investigation will be published in a separate paper.

During the years 1921 to 1925 I paid frequent visits to the Salt-lakes and collected specimens from different parts of the lakes at different seasons of the year.

The different stations selected by me for my collections are :—(*i*) the Dhappa Toll Office, (*ii*) Moheshathan, (*iii*) Hadia, (*iv*) Anandapur, (*v*) Krishnapur Bheri, (*vi*) Nolbena Bheri.

These saline swampy lands are chiefly inhabited by Bengali fishermen. who have built their thatched huts on comparatively

raised plots of land within the Salt-lakes. They take lease of these lakes and their subsistence mainly depends on pisciculture. Plate II shows the nature of the huts and type of people living in the Salt-lake region.

CHAPTER I.

Geography of the Lakes.

(i) *Their Position and Character.*

The Salt-lakes are formed of a considerable number of depressions filled with saline water and surrounded by, or alternating with, extensive stretches of marshy lands. They are situated south-east of Calcutta, in the district of 24-Parganas in Lower Bengal, covering an appreciable part of the Gangetic Delta, which is intersected by a network of rivers, shallow channels and creeks. The precise geographical position of the lakes is between 22°27′ and 22° 36′ N., and longitudes 88°24′ and 88°30′ E.

The boundaries of the Salt-lakes are not quite clear cut, because some of the portions of the lakes are being gradually converted into cultivated land; but approximately they are bounded on the north by the Kristopore Canal, on the South by the Tolly's Nala, on the East by the Kristopore Canal and the Bidyadhari river and on the West by the Eastern Bengal railway line to Port Canning. The map (Plate I) attached to this paper will show the exact position and boundary of the lakes.

(ii) *Their Divisions.*

The Salt-lake area is mainly divided into two almost equal parts, a Northern and a Southern part, by the "New-cut Canal," and the "Central Lake Channel." The Northern lake is bounded on the North and East by Kristopore Canal and on the South and West by the New-cut Canal and the Central Lake Channel. The

Southern lake is bounded by the Central Lake Channel and the Bidyadhari river on the North and East, the Tolly's Nala on the South and the village of Gharia and the Eastern Bengal Railway line to Port Canning on the West. Both of these lakes are further subdivided into smaller areas filled with salt water and surrounded by small narrow mud bunds as shown in the map (Plate I).

(iii) *General Features of the Lakes.*

"The western portion of this lake above Dhappa is open and fairly free from jungle. It is a swamp more or less divided into shallow tanks by small embankments on the edges of the little khals. These tanks or bhils are sometimes open; the greater portion of this lake is let out for fishing. The small embankments referred to have been made for fishing purpose. The water is allowed to fill into the embanked portions with the rising tide. When the tide recedes, nets or fishing boxes of bamboo are fixed at the outlets to catch the fish as they go out with the falling water. Sometimes bunds are thrown across the entrances to the embanked areas, and the fish are kept as prisoners until it suits the convenience of the lessee of the fishery to catch them." (*1*)

Plate II is an illustration to the above statements.

(iv) *Water Supply of the Lakes.*

"The Southern salt-lake is to a large extent open to a free tidal spill coming from the Matla, the Peali and the Bidyadhari series of rivers and finally entering into the Central Lake Channel and other Canals connected with it. There are hardly any marginal embankments to the khals connecting the Southern lake. The Northern lake receives its supply of tidal water entirely from the eastern Canal.* The principal Khals by which the tide enters this lake are the Nowbhanga khal, the Paran Chaprasi's khal and the Hatgachia khal."(*1*)

* By the eastern canal is meant the Central Lake Channel.

These khals vary from 100 to 250 ft. in width at their mouths, and the depths of water have been found to be $3\frac{1}{2}$ and 5 fathoms at low water respectively. "From these main khals there are endless ramifications of smaller creeks by which the water is spread over the face of the swamp. The edges of these khals are somewhat raised, and in many cases there are small embankments 12 or 19 inches high along the banks of them." (*1*)

Moreover, these salt-lakes are also indirectly fed by the sewage outlet coming from Entally and falling into the Central Lake Channel between the Paran Chaprasi's khal and Bantola Ferry. The storm-water outlet starts from the pumping station at Baliganj and falls into a khal near Bantola Ferry. Further down there is another khal known as the Baynala khal which carries a considerable amount of dirt and silt and meets the Bidyadhari river at the village of Baynala.

(*v*) *Bottom.*

The bottom of the lakes is muddy in consequence of the constant deposition of layers of silt. The mud is heavy and is composed of a rather tenacious loam, mixed with a certain proportion of fine sand characteristic of the creeks and canals in the Gangetic delta. The colour of the mud is bluish grey due to the presence of much humus. The surface of this mud is sometimes covered with a thin coating of river slime. There are two distinct layers, especially in the flowing water of the canals and khals; one of these is the layer of suspended particles of mud, and the other is the bottom layer. The bottom layer remains practically undisturbed, while the mud usually held in suspension is here and there only deposited as a top stratum at some corner where the water is stagnant.

The lakes are noticeable for their entire absence of any phanerogamic plant rooting in the bottom stratum. This is due to light being unable to penetrate deeper down in the water, owing to the muddy condition of the water, to the constant deposition of silt at the bottom, to the salinity of the water, to the action of the

tide and finally to the influence of human agency. But it is to be noted that there is an abundance of algae, especially of Cyanophyceae, and Diatomaceae either floating or forming a thick deposit at the bottom of the lakes and shallow depressions or on muddy soil of the swamps. The blue-green algae frequently stain the water bluish green.

(vi) *Depth.*

The whole of the Salt-lakes, except the canals and some larger khals and nalas are exceedingly shallow. The average depth of the lakes varies from one to three feet.

HISTORY OF THE LAKES.

The Salt-lakes occupy, as has already been said, a large portion of the alluvial plain of Lower Bengal, the whole of which is a comparatively recent geological formation, and the process of extension of that plain is here going on before our eyes.

(*a*) *Origin.*—The present condition of the Salt-lakes suggests that they were the bed of some large distributary of the present Hugly which was blocked by sand banks deposited somewhere in the South, after having its overflow discharged into the Matla and the Bidyadhari rivers. This bed together with the bhils situated along the bank of the dead river forms what we call the Salt-lakes, which are still fed by the tidal water coming from the Bidyadhari and the Matla rivers. Even to-day we can see at low tide how some parts of the moribund Bidyadhari river are thus being converted into Bheris or Salt-lakes and marshes.

(*b*) *Past condition of the lakes.*—Capt. Claud Martin's map of 1760 to 1764 shows two distinct divisions, one to the east and the other to the west bisected by an intervening channel connecting them. The map further shows that about a century ago no communication whatever existed between these lakes and the Hugly. The water supply of these lakes was then entirely tidal, being

derived directly from the sea by a deep winding creek which flows from the most southerly point of the lake and joins itself with another Sundriban Canal.

(*c*) *Unhealthy state of the lakes.*—The lakes were in former times a terrible nuisance to the town of Calcutta, and they were a dangerous place swarming with bacteria of many deadly diseases and people dwelling there at that time were " subject to constant low fevers, spleen, dropsy and mesenteric diseases; to new comers a residence of even a few days is almost sure to be fatal."(*1*)

Duncan Stewarts' evidence which was given during the Municipal enquiry of 1836 runs as follows:

" Mr. Charnock could not have chosen a more unhealthy situation on all the line of rivers, for three miles to the eastward is a salt water lake, which overflows in September and October and prodigious numbers of fish resort there: but in November and December when the floods are dissipated, those fishes are left to die, and with their putrefaction affect the air with thick stinking vapours which the North-east winds bring with them to Fort William, so that a great yearly mortality is caused by them." (*1*)

Even to-day, in spite of the great improvement effected in these parts during the last years, still the dying rivers and creeks together with the swamps are a great menace to the town of Calcutta, and if precaution is not taken at an early date, a single flood will expose the people of Calcutta to epidemics.

(*d*) *Improvement effected in the salt-lake region.*—The first communication between the Salt-lakes and the river Hugly was effected by Major W. Tolly by excavating a canal called after his name " Tolly's nala " under the terms of contract made with the Government in 1777. A second canal was opened during 1806 to 1810 known as the Belliaghatta Canal. A third was cut in 1857, called the New-cut Canal which joins the Central Lake Channel and finally the Bidyadhari river dividing the Salt-lakes into Northern and Southern divisions. Another canal, known as the Circular Canal was opened in 1833. The sewage and the storm-water outlets connected the Central Lake Channel in 1833. In 1910 another canal was cut on the eastern side of the lake called the

Kristopore canal. This canal starts from the New-cut Canal at Shambazar khal and connects the Bhangar Kata Khal at the village Sitalata on the South-eastern extremity of the lakes. [See map (Plate).]

(e) *Area and change of position of the lakes.*—The total area of the lakes is about 17,000 acres or about 26 sq. miles. They were originally at the foot of a ' mound ' or ' tumulus ' of about 30 ft. in height in the village of Ram Kissenpore, a mile from the high road leading to Dum Dum (*1*). This mound was raised up by Burmese Mug traders, and it served the purpose of anchoring their boats. But the lakes have now receded more than a mile from its former situation, and during the past years they have contracted considerably.

(*f*) *Land formation of the lakes.*—These swamps and the bottom of the lakes are gradually raised by constant deposition of silt and are soon overgrown by *Suaeda maritima*, which is interspersed at some places by *Cynodon dactylon* and *Fimbristylis ferruginea;* these act as sand binders in arresting the seeds of many littoral plants, chiefly of *Suada maritima*, *Avicennia officinalis*, *Acanthus ilicifolius* and others which are carried away by the tide along with the silt and humus. The seeds, after being deposited on muddy soil, germinate and give rise to mangrove formation. These littoral plants soon send out a network of suckers, from which develops a regular assemblage of pneumatophores, which help further in arresting the silt and thus raise the level of the land and give origin to the formation of regular swamp forests. These forests, in course of time, are cut down by fishermen and the land soon becomes dry and quite habitable.

HYDROGRAPHY OF THE LAKES.

(i) *Salinity of the Water.*

The salinity of the water of the lakes is the most important edaphic factor of the flora of the Salt-lake region. Profuse white incrustations of salt on the large area of the Salt-lake region during the hot months and also isolated patches of thick deposit of salt on

the bunds and embankments and dry parts of the lakes at other seasons indicate that the water of the lakes contains a large percentage of salt. (See Plate III.)

(ii) Level of the Lakes.

"In 1830 the average level of the northern salt lake was reported to be 0.0 mean sea level. In 1865, it had risen to 1.75 mean sea level. In 1882, the levels were shown on a plan and it was stated that 'In the lowest part of the lake the ground level is about 4.00 mean sea level.'"

"In 1913 further levels of this lake were taken which showed that the lowest level in isolated small areas was a little below 4.00 mean sea level and that the general level excluding village sites lay between 4.00 and 6.00 mean sea level, the lowest portion being on the western portion above Dhappa."

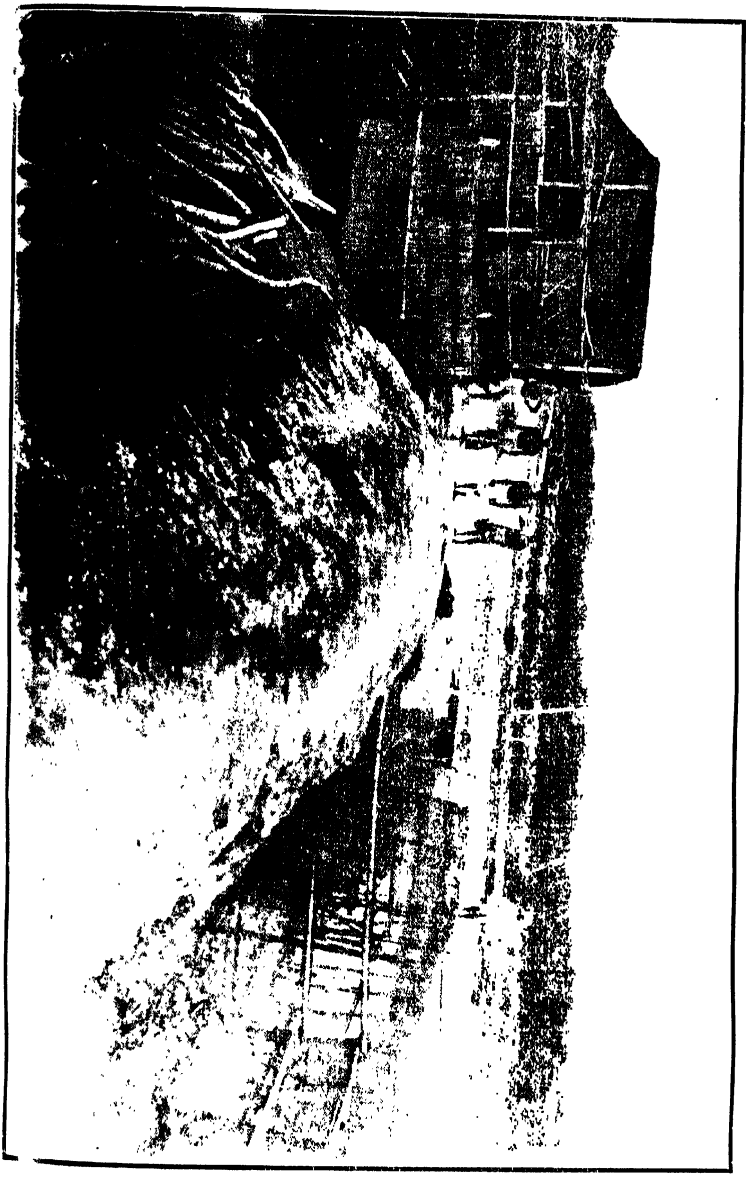
"The level, therefore, appears to have risen between 1830 and 1832, after which it does not appear to have materially altered, and it is probable that the same applies to the southern lake, the level of which in 1913 was much the same as in the northern lake. In the latter year embankments existed along the margins of all the khals leading from the river, and most of the tributary khals were closed with cross dams. The mouths of the Nowbhanga, Paran Chaprasi's, Bantala and Byar Khals were the only ones unclosed. In 1865 the southern bank of the Central Lake Channel was wholly "unembanked;" now it is fully embanked except at the above khals."(2).

(iii) Effects of Winds and Tides.

The Salt-lakes are quite open to the occasional cyclonic storms coming from the Bay of Bengal which cause considerable damage to the forest in the lake region. They are also exposed fully to the South-East Monsoon wind, which gives to many of the trees a gnarled and stunted appearance characteristic of the mangrove forests. The soil in these forests is also occasionally flooded with tidal water and the roots of the trees, like those of the mangrove swamps, produce a large number of pneumatophores varying from 6 to 18 inches in height. (See Plates III and V.)

Plate II.

K. P. Biswas.—



Huts, nets of bamboos, and type of people living in the Salt-lake region with white encrustation of salt on the embankment.

(iv) *Temperature and* (v) *Rainfall.*

The monthly mean of the maximum and minimum temperature as well as the rainfall recorded at the Alipur Observatory, which fairly represent this part of the district, is given in the following table.

Months.	Maximum temperature.	Minimum temperature.	Rainfall.
January ...	77.3	55.5	0.34
February ...	82.0	60.0	1.10
March ...	90.9	69.3	1.44
April ...	95.6	75.7	1.89
May ...	94.5	77.5	5.75
June ...	91.5	78.8	11.90
July ...	88.4	78.6	12.51
August ...	87.6	78.4	12.69
September ...	88.0	78.0	9.87
October ...	87.2	74.3	4.19
November ...	82.0	64.3	0.66
December ...	77.0	56.0	0.20
Year ...	86.8	70.5	62.54

ANIMAL LIFE OF THE LAKES.

The animal life of the lakes is very varied. But the lakes appear to be especially suited to the growth and development of fishes, and in fact a considerable amount of fish is supplied to the Calcutta markets. The holes along the edge of the canals and khals are chiefly occupied by crabs. Warming's statement regarding the crustacean fauna of littoral swamp-forests that " many crustacea belonging to various genera live here, burrow in the ground, bury dead leaves, and play a part similar to that played by earthworms in non-saline humose soil " will probably be found

applicable also to the Salt-lake region. Various kinds of worms and insects too inhabit the mud and dry earth. The water of the lakes, on the other hand, swarms with bacteria, protozoa and the Cyclopida, which form an important part of the plankton fauna of the lakes. Ants and spiders are very common and they mostly live on trees. The nests of spiders on the branches of the trees are striking sights of the forests of the lake region. Among the birds we notice vultures, eagles, many kinds of herons and water fowls; snipes too are common. The lakes are, therefore, undoubtedly a good field both for the botanist as well as of the zoologist.

Vegetation of the Lakes.

Three zones of the vegetation of the Salt-lakes may be distinguished, namely:

(1) The Vegetation of the embankments and bunds.
(2) The Vegetation of the Salt-lakes proper.
(3) The Vegetation of swamps which are partly dry and partly flooded in summer.

These three Zones represent in the restricted sense the mangrove formation of the Sundribuns further south.

General Character of the Vegetation.

(1) *Vegetation of the embankments and bunds.*

The embankments and bunds of Khals and Bheris are lined by a mixed formation of herbs and shrubs growing side by side along the edges of the Canals, Khals, and Bheris. Among the herbs *Fimbristylis ferruginea* forms, especially during the rainy season, along the sides a sort of carpet interspersed with small bushes of *Suaeda maritima* and frequently of *Heliotropium curassavicum*, alternating with isolated taller specimens of *Tamarix gallica*, var. *indica* and dense patches of *Acanthus ilicifolius*. This storey of herbs and bushes is overtopped by an upper shrubby storey, composed of *Excoecaria Agallocha* and *Avicennia officinalis* and now and then of dwarf hedges of *Clerodendron inerme.*

(2) *Vegetation of the Salt-lakes proper.*

The vegetation of the Salt-lakes proper is chiefly composed of algae, either floating as plankton or forming thin layers on the mud at the bottom or floating in thick blue-black or bluish green layers of considerable width attached to the haulms of grasses and other smaller partly submerged plants along the margin of the lakes. The algae belong to the class Cyanophyceae and most of them are members of the family of Oscillatoriaceae. These are associated here and there with shrubby specimens of *Aegiceras majus* or small bushes of *Phragmites Karka* within the shallower parts of the lakes. (See Plate IV.)

(3) *The vegetation of swamps and drier lands.*

The vegetation of swamps and comparatively drier lands **is** very interesting. Here we can distinguish three storeys of vegetation. The first storey is composed of a microphyte formation of algae belonging to the family of Oscillatoriaceae, of which *Oscillatoria princeps*, *Oscillatoria limosa* and *Oscillatoria lactevirens* form the dominant species. The thick deposit of these algae consists of blackish green, blackish brown or blue-green membranes, extending over a considerable portion of the surface of the muddy soil. The algae after drying up form deep black or brownish black sheets, which after being separated from the soil are carried about by winds from one place to the other or, when they are fresh, are dislodged from the soil by the current of water and are carried down to different parts of the lakes ; thus, they are distributed all over the surface of the lakes. It appears that these Oscillatorias are especially adapted to grow in filthy water; and in fact, they can be taken as indicators of foul water. The surface of the water is again covered with a thin yellowish green film of *Euglena* sp., associated with *Pandorina morum*, *Arthrospira platensis* and species of *Oscillatoria* and *Diatoms*, floating as plankton between the trees in stagnant water in which bubbles of gas rising from the bottom burst at the surface. Among other plankton algae mention must be made of the well known *Clathrocystis aeruginosa*, which floats freely on the surface of the water

of the canals, lakes and khals, presenting to the naked eye a finely granular appearance and colouring the water beautifully blue-green, which when dry look like indigo paint along the sides immediately above the water; associated with this is also found *Oscillatoria cf. subsalsa*. Among the green filamentous algae *Enteromorpha intestinalis*, *Enteromorpha prolifera* and *Chaetomorpha Linum* are quite abundant and float in masses on the surface of the water, though at first attached to the substratum. *Protococcus viridis*, which forms a powdery coating on the bark of *Avicennia officinalis*, *Excoecaria Agallocha* and *Sonneratia apetala* also grows on the surface of the rhizophores rising above the water.

The second storey is composed of phanerogamic plants of *Suaeda maritima* which grows in bunches all over the marshy lands interspersed with *Heliotropium curassavicum* and taller plants of *Excoecaria Agallocha* up to the outskirts of the forest chiefly composed of *Avicennia officinalis*.

The third, the tallest storey, consists chiefly of a mixed formation of *Avicennia officinalis* and *Aegiceras majus*, which vary from 10-20 ft. in height, The interior of the forest is more or less clear of any undergrowth, the soil being covered with large patches of algae. The rhizophores and spreading sheets of algae and rarely a few bushes of *Suaeda maritima* form a characteristic feature of the forest floor. (See Plate III.) This forest, composed mainly of *Avicennia officinalis*, contains sometimes a few plants of *Sonneratia apetala*, which is the tallest tree of the lake region growing to a height of 20 to 40 ft. *Sonneratia apetala* forms sometimes a nearly pure association in some parts of comparatively dry and high lands. (See Plate V.)

The lands situated along the sides of the Kristopore Canal are at present practically all converted into cultivated lands and the open uncultivated areas are overgrown with the common weeds of Bengal, such as *Malachra capitata*, *Cleome viscosa*, *Cassia Tora*, *Cassia Sophera*, *Cassia occidentalis* and others, forming the chief constituents. Among the trees and shrubs *Acacia arabica* forms an important feature of the landscape, especially along the sides of the Kristopore Canal. Some of the drier and

higher parts of the lakes are covered with a dense undergrowth of the common weeds interspersed chiefly with taller specimens of *Acacia arabica*, and scarcely a few other shrubs.

The fact is that, as the saline soil is gradually covered up by ordinary soil and thus raised, the common Bengal plants settle there and grow as they grow elsewhere. Hence it is hardly of any use to add a complete list of all these common Bengal plants which are daily encroaching upon the higher and drier and comparatively nonsaline parts of the lakes and which are rapidly increasing both in the number of individuals and in the number of species.

Euphorbia antiquorum is present in the more or less semi-desert and rather sandy parts of the lakes. Solitary species of *Sida* and other genera are also found to grow gaining a foothold here and there.

A systematically arranged list of plants characteristic of the Salt-lake region is appended at the end of the memoir.

Aims of the botanical survey of the lakes.

My main object in studying the vegetation of the lakes is to preserve a record of the flora of the Salt-lake region which, it appears, will be reclaimed in future and after the lapse of a century there may not be any trace left of the present lakes. On the other hand, it is very interesting and important to compare the algae of the saline tidal water with those of fresh water. We can observe also the difference in the growth of these halophytic algae, their morphological and physiological changes when they are subject to different environmental factors and when they are kept in the laboratory under culture. Further, an investigation into the change of colour in some of the algae such as, *Oscillatoria limosa*, *Oscillatoria princeps*, *Oscillatoria laetevirens* and others, as they are found to grow differently coloured in different parts of the lakes, is sure to throw some light on the problem of the change of colour in algae.

Methods and Material.

To reach the interior of the lakes through the Canals and Khals, it is best to go by one of the country boats called dinghis. But for getting into the shallower portions a " dug-out " is the most useful; though often one has to wade through the marshy grounds or walk along the embankments to collect in the interior of the forest and swamps and to observe the growth and the nature of habitat of the plants specially of algae. It may be mentioned that in the Canals, I have more than once availed myself of the motor-boat, belonging to the Public Works Department, kindly placed at my disposal by Mr. D. N. Sen Gupta, Executive Engineer, Circular and Eastern Canals Division, Irrigation Department, P. W. D., Bengal.

(i) *Apparatus.*

A plankton net about 2 ft. long, a ' Diatom sucker,' a rope dredger with a large brass hook tied to it, employed for dragging aquatic plants from the bottom and a cylindrical tin box $6'' \times 3''$, tied to the hook of the rope dredger serving the purpose of lifting mud from the bottom, a couple of netted wire presses, a leather holdall and tin vasculums, envelopes and a packet of mounting paper constituted my collecting outfit.

(ii) *Collections.*

My collections including the type specimens of new species and others are at present kept in the Botanical Laboratory of the University College of Science, Baliganj, Calcutta. Almost all the phanerogamic plants found in the region have been mentioned by Sir David Prain in " The Vegetation of the Districts of Hughli-Howrah and the 24-pergunnahs " (see Records of the Botanical Survey of India, Volume III, No. 2), except *Heliotropium curasavicum* which appears to be newly introduced. A few algae have also been reported by him in the same volume and a description of each of them has been given in this paper after placing them in their proper systematic order.

Conclusion.

Certain blue-green algae, particularly species of Oscillatoria, grow most luxuriantly during the rains all over the lakes and swamps. During the hot weather *Pandorina Morum*, *Enteromorpha prolifera* are very common. Considerable changes in the algal flora of lakes and swamps accompany periodic changes in climate and in the salinity of the water. A further detailed study of these changes will undoubtedly prove to be of considerable interest. The want of funds usually renders studies of this nature a matter of considerable difficulty, and the marshy ground, the unsavoury character of the Lakes and their surroundings, particularly in the northern parts, and the unhealthy conditions of the localities place considerable obstacles in the way of the investigator.

Acknowledgments.

I am indebted to my revered and learned teacher, Professor Dr. P. Brühl, the University Professor of Botany, for going through my paper and to Mr. Addams-Williams, C.I.E., Chief Engineer and Secretary, Irrigation Department, P. W. D., Bengal, for giving me valuable information with regard to the topography of the Salt-lakes. My thanks are also due to my brother Mr. R. N. Biswas, surveyor, Land Acquisition Department, Alipur, who helped me in every possible way to make the botanical survey of the lakes a success; and lastly, to my friend Mr. A. C. Mitra, B.Sc., for taking the Photographs of the lake region, contained in this paper.

References.

(1) Selections from the Records of the Bengal Government Papers from 1865 to 1904.

(2) History of the rivers in the Gangetic Delta, 1750—1918, by C. Addams Williams, Esq., C.I.E., Chief Engineer and Secretary, Irrigation Department, P. W. D.

CHAPTER II.

LIST OF PLANTS FOUND IN THE SALT-LAKES.

This list contains all the plants reported by previous authors as well as those which have been found by myself.

ALGAE.

I. MYXOPHYCEAE.

(i) Family—CHROOCOCCACEAE.

1. *Gloecapsa aeruginosa* (Carmich.) Kuetzing.

Kuetzing, Tab. Phyc., t. 21, fig. 11; Kuetz., Sp. Algar., p. 218; Rabenhorst, Fl., Eur. Alg. II, p. 39; Cooke, Brit. Freshw. Alg., p. 207, t. LXXXIV, fig. 2; Hansg., Prodr. II, p. 153; Haematococcus aeruginosus, Hass., Freshw. Algae, p. 833, n. 15, t. 82, fig. 3; Tilden, Minnesota Algae, vol. I, p. 18, t. 1, fig. 19; De Toni, Sylloge Algarum, Myxophyceae, p. 55.

Plant mass crustaceous or cartilaginous, blue-green or throughout grey-green; colony 9-25 (50)μ in diameter, spherical or slightly angular by mutual pressure, sheaths colourless, indistinctly lamellose; cells spherical or angular by mutual pressure, 4-8μ with the sheath and 2-4μ, without the sheath; contents granular, blue-green.

Habitat.—Forms blue-green crusts on canal banks, Salt-lakes, near Calcutta, *see* Plate VI, Fig. 1.

PLATE III.

K. P. BISWAS.

The interior of the forest of *Avicennia officinalis* with pneumatophores and deposits of bluegreen algae.

2. *Clathrocystis aeruginosa* (Kuetz.) Henfrey.

Cooke, Brit· Freshw. Alg. p. 212, t. LXXXVI, fig. 7. a-b; Microcystis aeruginosa Kuetz. Tab. Phyc. I, t. 8; Polycystis aeruginosa Kuetz., Sp. Alg., p. 210; Hansg., Prod., II, p. 146; De Toni, Syll. Alg., Myx., p. 94; Tilden, Minnesota Algae, vol. I, p. 37, t. II, figs. 21, 22.

Plant mass forming a bright blue-green scum on the surface of the water and floating in vast strata in fresh-water tanks, pools and lakes as well as in brackish-water canals and lakes, presenting a finely granular appearance to the naked eye and painting the sides of the canals, pools, tanks and lakes with a bright blue-green or indigo colour ; when the plant mass dries up it appears as a crust of indigo colour. The plant lasts throughout the year forming the most common plankton of our tanks, pools and lakes and grows most luxuriantly during the hot months just before the rains from May to June. But after the first showers of monsoon rains a large number of colonies dying and producing a considerable amount of organic matter, putrefaction bacteria cause a rotting, stinking odour. It appears after the rains and grows more healthily in running water than in stagnant water, though it is quite common in both of them and is often associated with other plankton algae. The colonies are of various shapes, spherical or elongate with irregularly lobed margins, solid when young but becoming clathrate and saccate " until the whole becomes a coarsely latticed sack or clumsy net of irregularly lobed forms." The colonies are surrounded by a hyaline diffluent sheath and vary from 30-130 μ in diameter ; the cells are spherical, 3-4μ in diameter, very numerous in each of the colonies, the contents are granular and blue-green.

Habitat.—Floating as plankton in the canals, khals and nalas and lakes, Salt-lakes, near Calcutta. I have also found this alga floating as plankton in the Buckingham canal, Madras, and in a pool in the valley of the Pareshnath Hill in Sontal Pergunnahs. *See* Pl. VI, fig. 2. (*a-d*).

(*ii*) Family—OSCILLATORIACEAE.

3. *Oscillatoria princeps* Vauch.

Kuetz., Tab. Phyc. I, t. 44, fig. 4; Rab., Fl. Eur. Alg. II, p. 112; Gom., Mon. des Oscill., p. 206, t. VI, fig. 9; Wolle, Freshw. Alg. of U. S., p. 317, t. CCVII, figs. 20-22; De Toni, Syll. Alg., p. 150 ; Tilden. Minnesota Algae, p. 62., t. IV, fig. 3; Commentationes Algologicae, in Journal of the Department of Science, vol. VII, Road Slimes of Calcutta by K. P. Biswas, p. 4; Oscillaria maxima Kuetz. Tab. Phyc. I, p. 32, t. XLIV, fig. 41; Sp. Alg., p. 248 ; Osc. princeps et maxima Rab. Fl. Eur., Alg., II, p. 112 : Osc. imperator Wood., Wolle, Freshw. Algae of U. S., p. 317, t. CCVIII.

Plant mass either verdigris-green, blackish green or almost black when floating in shady stagnant water or brownish green or bluish grey when forming a membrane on the exposed surface of the soil ; filaments 30-33 μ (16-60μ) in diameter, straight or curved, elongated, entangled, somewhat fragile, slightly attenuated; apex obtusely rounded, truncate, apical cell more or less convex, not capitate ; cells 2.5-3μ (3.5-7μ) in length, very slightly or not at all constricted at the joints, transverse walls not granulated ; cell contents uniformly granular, bluish green.

Habitat.—Salt-lakes, near Calcutta ; common. *See* Plate VI, fig. 3.

4. *Oscillatoria limosa* (Roth) Ag.

Hass., Brit. Freshw. Alg., p. 246, t. LXXI, fig. 2; Gom., Mon., pp. 210-211, t. VI, fig. 13; Cooke, Brit. Freshw. Alg., p. 251, t. XCVII, fig. 3; Os. Froelichii Kuetz. Tab. Phyc. I, p. 31, t. 43, fig. 1 ; Rab. Fl. Eur. Alg. II, p. 109 ; Oscillatoria **limosa** (Roth) Ag., *De Toni Syll. Alg., Myx., pp. 150-157 Tilden, Minnesota Algae, vol. I, p. 65, t. IV. fig. 6.*

Plant mass forming dark blue-green or brown or yellowish green membrane on the surface of the soil with the filaments growing side by side, which appear to the naked eyes as fine brownish dark lines ; filaments long, straight, or more or less curved, somewhat fragile, not at all or scarcely tapering, 10-15μ in diameter ; apex obtusely rounded, apical cell convex; cells 2-5μ in length, 3-6 times shorter than long, hardly constricted at the joints, transverse walls frequently granulated, cell contents granular blue-green or brown.

Habitat.—On muddy soil; in the Salt-lakes near Calcutta; common. *See* Plate VI, fig. (*a-d.*)

5. *Oscillatoria simplicissima* Gom.

Gom., Mon., p. 219, t. VII, fig. 1 ; De Toni, Syll. Alg., Myx., p. 165.

Stratum blackish green ; filaments long, thin, flexible, mixed up with other Oscillatorias ; yellowish green or bluish grey, straight, elongate, or more or less curved, not constricted at the joints, 8-9μ in diameter; straight towards the apex, not attenuated, not capitate ; cells shorter than the diameter, 3-6μ in length; contents finely uniformly granular, blue-green or bluish grey.

Habitat.—Salt-lakes, near Calcutta. *See* Plate VI, Fig. 8.

6. *Oscillatoria tenuis* Agardh.

De Toni, Syll. Alg., Myx., p. 116; Tilden, Minnesota Algae, V. I, p. 71, t. IV, figs. 17-18; Com. Alg. I, Algae of Bengal Filter-beds, by Paul Brühl and Kalipada Biswas, p. 6, t. 1, fig. 8; in the Journal of the Dept. of Science, C. U., vol. IV.

Filaments mixed with other algae in slimes formed on the roads near the Salt-lakes ; 9μ in diam. : cells 3μ in length.

7. *Oscillatoria amphibia* Aga

De Toni, Syll. Alg. Myx., p. 169: Tilden, Minnesota Alg., p. 73, t. IV, figs. 19-20; Com. Alg. I. Algae of Bengal Filter-beds, p. 4, t. 1, fig. 4.

The plant forms a deep blue-green stratum in the Salt-lakes on mud. It does not grow there luxuriantly; but when it is kept in fresh water it begins to grow very rapidly and forms a deep blue-green membrane, displacing all other algae from the culture. Filaments 2-3μ wide and cells 4-6 μ in length.

Habitat.—In the Salt-lakes, near Calcutta ; common. *See* Plate VI, fig. 9 (*a-b*).

8. *Oscillatoria minnesotensis* Tilden.

Tilden, Minnesota Algae, p. 75, t. IV, fig. 22.

Plant mass thin, membranaceous, dark blue-green; filaments long, straight, or more or less curved and flexuous, very rapidly moving, erect towards the apex, somewhat fragile, 2-3μ (5μ) in diameter; cells longer than broad, about 4 μ in length, constricted at the joints; apical cell round, subobtuse or somewhat conical; transverse walls not granulated; contents very finely granular, almost homogeneous.

Habitat.—In Salt-lakes, near Calcutta ; common. *See* Pl. VI, fig. 5 (*a-b*).

9. *Oscillatoria lacte-virens* (Crouan) Gom.

Gom., Mon., p. 220, t. VII, fig. 11; De Toni, Syll. Alg. Myx., p. 177 ; Tilden, Minnesota Algae, vol. I, p. 78, t. IV. fig. 28.

Plant mass forming a thin bright blue-green or yellowish green membrane, spreading on muddy soil and finally floating on the surface; but, when dry, forming black thin sheets; filaments long, straight or slightly curved, rapidly moving, fragile, 3-6μ in diameter, slightly constricted at the joints; apex of trichome briefly attenuated, undulating or hooked, rarely straight; apical cell sub-acute or acute, somewhat pointed, not capitate; calyptra none; cells 2-3μ in length; cell contents uniformly granular blue-green.

Habitat.—In Salt-lakes, near Calcutta; *see* Pl. VI, fig. 7 (*a-c*).

10. *Oscillatoria salina*, sp. nov.

Plant mass forming a deep blue-green thin membrane extending over the muddy soil and finally, after being separated, floating on the surface of water ; filaments lying side by side in the stratum, straight, elongate, erect, scarcely curved, fragile, rapidly moving, not at all constricted at the joints, 3-5μ in. diameter ; apex of trichome straight, briefly tapering, ending accuminately in a sharp point, hooked or twisted, not capitate ; apical cell mucronate hyaline ; calyptra none ; cells shorter than the diameter, 1.5-2μ in length ; sometimes, the filament is interrupted by inflated refringent cells ; transverse walls indistinct, not granulated; cell contents finely uniformly granular, almost homogeneous, blue-green.

Habitat.—In Salt-lakes near Calcutta ; common ; *see* Pl. VI, fig. 6 (*a-h*).

The plant differs from *Oscillatoria acuminata*. in having its cells much shorter than the diameter and never constricted at the joints ; transverse walls not at all granulated, contents uniformly granular, almost homogeneous. It differs from *Oscillatoria brevis* in having its apex briefly tapering and acuminately ending in a sharp point, the apical cell being mucronate and hyaline, transverse walls indistinct and only visible after killing and fixing and treating with iodine or chlorozinc iodide ; but, not becoming blue when treated with chlorozinc iodide.

11. *Oscillatoria formosa* Bory.

Kuetz., Tab. Phy. I, t. XLI, f. 8 : Gom., Mon., p. 230 ; Tab. VII, fig. 6; O. tenuis γ. formosa Kuetz, Sp. Alg., p. 242; Rab., Fl. Eur. Alg. II, p. 102; De Toni, Syll. Alg. Myx., p. 182.

Plant mass bright blue-green ; filaments straight or curved, elongate, somewhat flexible, slightly constricted at the joints, 3-4μ (4-6μ) in diameter ; apex of trichome somewhat obtuse, subacute and very briefly tapering, more or less hooked, not capitate: calyptra none; cells much shorter than long, 1.5-2μ in length, contents uniformly granular, blue-green.

Habitat.—In Salt-lakes near Calcutta, *see* Pl. VI, fig. 10 (*a-b*).

12. *Oscillatoria cf. subsalsa* Agardh.

Kuetz., Tab. Phyc. I, t. 42, fig. 5 ; Rab., Fl. Alg., II, p. 108; De Toni, Syll. Alg., Myx., p. 187; Tilden, Minnesota Algae, p. 83.

Plant mass floating as plankton, forming a bright yellowish green of bluish green film on the surface of water; filaments either short, needle like, about 100-303μ long or more, straight, somewhat fragile, scarcely constricted at the joints, about 7-9μ (8-10μ) in diameter ; cells twice as short as the diameter, 3-4μ (4-5μ) in length, transverse walls more or less pellucid; apex of trichome equal or slightly tapering, hardly beak-like, obtusely rounded : cell contents granular blue-green.

I have not seen the dark blue-green radiating and mucous stratum of this alga, as mentioned in De Toni, Syll. Alg. and Tilden's Minnesota Algae.

Habitat.—In Salt-lakes, Calcutta; common. *See* Pl. VII, fig. 11 (*a-c*).

13. *Spirulina maior* Kuetzing.

Gom., Monogr., p. 251, t. VII, fig. 29 ; De Toni, Syll. Alg. Myx., p. 210; Tilden, Minnesota, Alg., p. 87, t. 10, fig. 46; Spirulina oscillariodes Kuetz. t. Phyc. I, p. 26, t. 37, fig. 8; Sp. Alg., p. 236; Spirulina Oscillariodes Turp., Records of the Bot. Survey of India, Vol. III, No. 2, p. 333, Cooke, Brit. Freshw. Algae, p. 256, t. 96, fig. 3 ; Hansg., Prod. II, p. 120 ; Rab., Flora Eur. Alg., III, p. 419.*

Plant mass forming a deep blue, green or yellowish green stratum; trichome 1.2-1.7μ in diameter, usually scattered among other algae, more or less flexuous, twisted into a somewhat loose regular spiral, 2-3μ (4μ) in diameter, the distance between the turns being 3μ (2.7-5μ).

Habitat.—Forming a thin yellowish green or blue-green membrane on muddy soil,—Salt-lakes, near Calcutta, common. *See* Pl. VII, fig. 12 (*a-b*).

* It is Kuetzing who is the author of *Spirulina Oscillariodes* and not Turp.

14. *Phormidium tenue* (Meregh.) Gom.

De Toni, Syll Alg· Myx·, p· 227 ; Gom. Mon., p. 169, t. IV, figs. 23-25; Tilden, Minnesota Algae, vol. I, p. 98, t. IV, figs· 63-65 ; Com. Alg. I, Algae of Bengal filter-beds, p. 8, t. 11, fig. 13; in the Journal of the Dept. of Science, C. U., vol. IV.

Habitat.- Scattered among other algae in the Salt-lakes near Calcutta.

15. *Lyngbya crispa* Agardh.

Agardh., Syst., p. 74; Records. Bot. Surv. of India, vol. 3, No. 2, p. 333.

Agardh, and not Kuetzing is the author of Lyngbya crispa, and Kuetzing therefore describes *Lyngbya crispa* Agardh. in Sp. Alg., p. 283; Tab. Phyc., I, p. 48. t. 89; fig. 4. It is either *Lyngbya aestuarii* (Mert.) Liebm., De Toni, Syl. Alg. Myx., p. 262, or *Lyngbya majuscula* (Dillw) Harv. De Toni, Syl. Alg. Myx., p. 268, under both of which the above species has been included by De Toni.

16. *Lyngbya cinerescens* Kuetz.

Kuetz., Sp. Alg., p. 281: Rab., Fl. Eur. Alg. II, p. 148: Tab. Phyc. I, t. 88; fig. 3; De Toni, Syl. Alg. Myx., p. 268; Records, Bot. Surv. of India, vol. III, No. 2, p. 333.

Stratum bright blue-green, trichomes 7.5-15μ in diameter, pale blue-geen, very slightly constricted, sheath thick, hyaline.

Habitat.—Salt-lakes near Calcutta, *see* Pl. VII, fig. 16 (*a-c*).

17. *Hypheothrix tenax* Wolle.

Wolle, Freshw. Algae of U. S., p. 319, t. 308, fig. 2; De Toni, Syll. Alg., p. 329; Tilden, Minnesota Algae, p. 141; Hypheothrix tenax Mart. in Records of the Bot. Survey of India, p. 333.

Stratum sometimes expanded or at other times forming dirty olive-green small caespitose cushion-shaped clusters ; trichomes at first loosely flexuous and curved, but later on densely interwoven forming pale blue-green firm membranes or cushions, cells more or less equal, often indistinct, sometimes interrupted ; sheath colourless, somewhat firm, 35-50 μ in diameter.

Habitat.—Salt-lakes near Calcutta.

Wolle and not Martens is the author of this species.

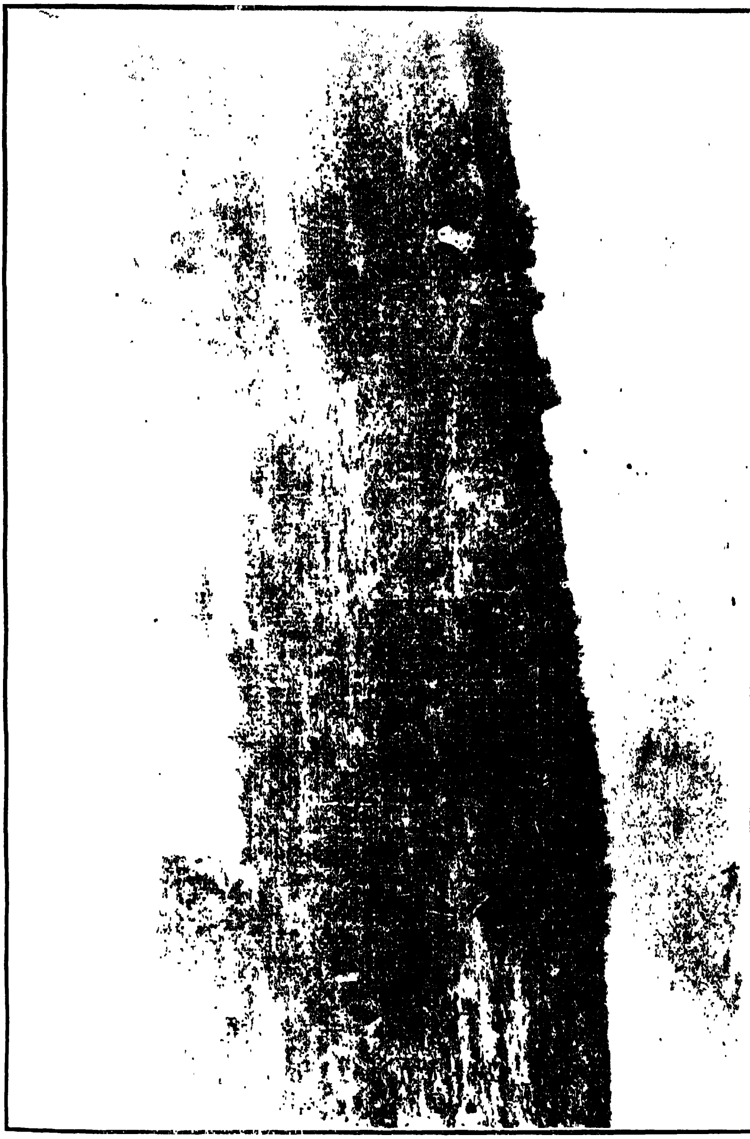
18. *Symploca hydnoides* Kuetz.

Gom., Mon., p. 106; t. II, fig. 1-3; De Toni, Syll. Alg. Myx., p. 300; Tilden, Minnesota Algae, vol. I, p. 129 ; Kuetz., Sp. Alg., p. 272; Tab. Phyc. I, p. 44, t. 76, fig. 11; Rab., Fl. Eur. Alg. II, p. 157; Gom., Mon., p. 107, t. II, figs. 1-4: Leibleinia Lenormandi Kuetz. in Bot. Zeit. V, p. 194; Hydrocoleum Lenormandi Mart. in Records of the Botanical Survey of India, vol. III, No. 2, p. 334.

Plant mass fasciculate, caespitose, dull rarely dark lead-coloured; fascicles up to 3 cm. in height, erect, spine-shaped, often lighter coloured at the base on account of the presence of empty sheaths ; filaments densely entangled agglutinated, sometimes with false branches unequally and angularly twisted; sheaths thin, somewhat mucous, becoming slightly blue with chlorozinc iodide ; trichomes blue-green, slightly constricted towards the apex, 6-8 μ in diameter, cells slightly longer than the diameter or twice as short as the diameter 5-14 μ in length : partition walls often indistinct, contents granular ; apical cell somewhat inflated, caryptra none.

Habitat.—Salt-lakes, near Calcutta, see Pl. VII, 15 (*a-b*).

Hydrocoleum Lenormandi Mart., mentioned by Sir David Prain as occurring in the Salt-lakes, is probably the same as *Leibleinia Lenormandi* of Kuetzing, which has been described under *Symploca hydnoides* Kuetz. by De Toni. There is no genus called *Hydrocoleus*, but there is one known as Hydrocoleum, *see* Kuetzing's Species Algarum, p. 258, which however does not include any species called "*Lenormandi,*" but *Hydrocoleus Lenormandi* is



Salt-lake proper with *Aegiceras majus* and *Phragmites Karka* on the foreshore.

same as *Leibleinia Lenormandi* of Kuetzing and *Symploca hydroides* Kuetz. of De Toni, Syll. Alg., Myx., p. 300.

19. *Symploca muscorum* (Ag.) Gom.

De Toni, Syll. Alg., Myx., p. 303; Tilden. Minnesota Algae, vol. I. p. 132, t. V, fig. 54. Gom., Mon., p. 110, t. II, fig. 9; Phormidium lyngbyaceum Kuetz., Sp. Alg., p. 255; Tab. Phyc. I, p. 33, t. 46, fig. III; Records of Bot. Surv. of India, vol. III, No. 2, p. 333; Tolypothrix coactilis De Bory, Rab., Fl. Eur. Alg. II, p. 278; Lyngbya phormidium Kuetz., Sp. Alg., p. 280 ; Tab. Phyc. I, p. 47, t. 86, fig. 4 ; Wolle, Freshw. Algae of U. S., p. 299, t. CCCI, fig. 22-26, Hansg., Prodr. II, p. 101.

Plant mass fasciculate, mucous, Phormidium-like, extended, dark-green, blue-green, or reddish-green in colour ; fascicles twisted, creeping, rarely erect ; filaments simple, flexible, densely crowded, at the base very much tortuous and interwoven, towards the upper portion less twisted somewhat parallel ; sheaths firm, tenacious or more or less mucous, blue-green with chlorozinc iodine, up to 2μ in thickness; trichomes blue-green not constricted at the joints, 5-8μ in diameter; length of cells almost equal to the diameter of the trichomes or twice as much as the diameter, 5-11μ in length; contents sparsely granular; transverse walls usually inconspicuous, not granulated ; apical cell round, obtusely conical; calyptra slightly thickened.

Habitat.—Salt-lakes, near Calcutta, *see* Pl. VII, fig. 13.

20. *Sirocoleus Kurzii* (Zeller) Gom.

De Toni, Syll. Alg., Myx., p. 380. Chthonoblastus Kurzii Zeller in Journ. of As. Soc. of Bengal, XLII, Part II, p. 178, Hydrocoleum Kurzii Mart. in Records of Bot. Surv. of India, vol. III, No. 2, p. 334.

Plant mass caespitose, penicillate, soft, floating now and then, dark-green or bright-green; filaments with false branches, the false branches adpressed ; sheath hyaline, mucous, somewhat thick,

superficially smooth or rough, corrugated, closed at the apex and acuminate or open, trichomes pale blue-green or violet, parallel, somewhat erect or twisted like a rope, acuminate at the apex, not constricted at the joints, 7-10μ in width; cells 2-4 times shorter than the diameter, 2-4μ in length; transverse walls frequently granulated, apical cell obtuse, conical.

Habitat.—Muddy banks of canals, also in Salt-lakes.

There is no species called *Hydrocoleum Kurzii* Mart. as reported by Sir David Prain in the Vagetation of the districts of Hughli-Howrah and the 24-Pergunnahs. The genus is at present known as Hydrocoleus and not Hydrocoleum. *Hydrocoleum Kurzii* is evidently the same as *Sirocoleus Kurzii* of Gomont and *Chthonoblastus Kurzii* of Zeller.

21. *Microcoleus Chthonoplastes* (Fl. Dan) Thuret.

De Toni, Syll. Alg., Myr., p. 371; Tilden, Minnesota Algae. vol. I, p. 255, Pl. VI, fig. 28, Cooke; Brit. Freshw. Algae, p. 255, tab. C, fig. 1; Chthonoblastus salinus Kuetz. Sp. Alg., p. 262; Tab. Phyc. I, p. 38, t. 58, f. 2; Rab., Fl. Eur. Alg. II, p. 133; Microcoleus gracilis, Hass., Brit. Freshw. Alg., p. 261, tab. 70; fig. 2; Wolle, Freshw. Algae of U. S., p. 306, tab. 203, fig. 10-11; Cooke, Brit. Freshw. Alg., p. 255, tab. XCIX, fig. 1; Chthonoblastus Lyngbyei Kuetz Sp. Alg., p. 262; Tab. Phyc. I, p. 38, tab. LVIII, fig. 1; Microcoleus Chthonoblastus B Lyngbyei, Hansg. Prod. II, p. 77; Microcoleus anguiformis Harv. in Hass. Brit. Freshw. Alg., p. 261, t. LXX, fig. 1; Wolle, Freshw. Alg. of U. S. p. 306; Chthonoblastus anguiformis Kuetz., Sp. Alg., p. 262, Tab. Phyc. I, p. 38, tab. 57, fig. 1; Rab. Fl. Eur. Alg. II, p. 133; Microcoleus Lyngbyei Kg.; Records of the Bot. Surv., vol. III, No. 2, p. 334.

Filaments twisted, rarely branched, forming a dull or dark-green, broadly expanded, compact, stratified mass, made up of layers of different colours, or growing sparsely among other algae; sheath cylindrical, more or less unequal roughened in outline, usually opened at the apex, entirely diffluent, not blue with chlorozinc iodine, trichomes bright blue-green, short, somewhat

erect, many within the sheath, usually densely aggregated in fascicles, rarely twisted in the form of a cord, 2.5-6μ in width cells more or less equal to the diameter or twice as long as the diameter 3.6-10μ in length; transverse walls not granulated; apical cell not capitate, acute-conical.

Habitat.—Calcutta Salt-lakes, *see* Pl. VII, fig. 17 (*a-c*).

Kuetzing does not mention any species known as *Microcoleus Lyngbyei* Kg., reported by Dr. Prain; he (Kuetz) is the author of the species called *Chthonoblastus Lyngbyei*, which is evidently the same as *Microcoleus Lyngbyei* mentioned by Sir D. Prain. Kuetzing's *Chthonoblastus Lyngbyei* is again included in *Microcoleus Chthonoplastes* (Fl. Dan) Thuret, by De Toni.

22. *Calothrix Juliana* (Menegh) Bornet et Flah.

Leibleina Juliana Kuetz.; Records of Bot. Surv. of India, vol. III, No. 2, p. 333; Sp. Alg., p. 276 ; Tab. Phyc. tab. 82, fig. IV; De Toni, Syll. Alg. Myx., p. 605; Tilden's Minnesota Algae, vol. I, p. 256, Pl. XVI. fig. 5.

Filaments scattered or forming an interrupted, olivaceous stratum, when dry of amethyst colour, densely crowded, erect, simple, rigid, 2 mm. in height, 10-15μ in diameter, often thickened at the base, sheath, thin close, not lamillose, colourless; trichomes 9-12.5μ in width ending in a long tapering fragile hair; cells three times shorter than their diameter; hormogones 4-5 times longer than their diameter.

Habitat.—Salt-lakes, Calcutta, *see* P. VII, fig. 14.

23. *Leptothrix mamillosa* Menegh.

Kuetz., Sp. Alg., p. 264; No. 17; Records of the Bot. Surv. of India, vol. III, No. 2, p. 334.

Trichomes, 1μ in thickness, curved, intricate, in a hemispherical swollen reddish body.

Habitat.—Salt-lakes near Calcutta.

(*iii*) Family—SCYTONEMACEAE.

24. *Scytonema granulatum* Martens.

De Toni, Syll. Alg. Myx., p. 537; Prain, Records of Bot. Surv. of India, vol. III, No. 2, p. 335.

The reference given in De Toni's Syll. Alg. with regard to this species, namely, Kurz in Proc. of As. Soc. of Bengal, XIII, p. 172, is evidently incorrect, as the species is not found reported there, but it is reported by Sir David Prain in the Record of Bot. Surv. of India, vol. III, No. 2, p. 355, in which no reference is made to the literature regarding the report of the species of algae mentioned therein.

II. CHLOROPHYCEAE.

(*iv*) Family—VOLVOCACEAE.

25. *Pandorina Morum* (Muell.) Bory.

De Toni, Syll. Alg., Chl., vol. I, p. 339; Rab., Fl. Eur. Alg., p. 99; Hansg., Prodr., p. 103, n. 139; Wolle. Freshw. Algae of U. S., p. 161, tab. 153, fig. 1-10; Botryocystis Morum Kuetz, Species Algarum, p. 208, Tab. Phyc. I, tab. 19, fig. 65; Botryocystis Volvox Kuetz, Tab. Phyc. I, tab. 9, fig. 64; Sp. Alg., p. 208.

Colonies spherical or oblong-elliptical, 20-40μ (up to 200) in diameter, consisting of ten or 8-16 rarely of 32 cells; cells 9-12μ by 6-12μ (15μ) the epispores of the zygotes smooth.

Hab.—Floating in a nala in Salt-lakes, covered with a film of *Euglena* sp. See Pl. VII, fig. 18 (*a-b*).

(*v*) Family—PROTOCOCCACEAE.

26. *Protococcus viridis* Agardh.

De Toni, Syll. Alg., Chl., vol. II, p. 699, Pascher, Süsswasserflora, Heft 5, Chlorophyceae 2, p. 224, fig. 32; Pleurococcus vulgaris Naegeli, Pleurococcus Naegelei Chodat. Kuetz.

Tab. Phyc. I, tab. 3; Rab., Fl. Eur. Alg. III, p. 56; Hansg. Prodr., p. 141; Cooke Brit. Freshw. Alg. III, p. 29, tab. 12, fig. 1; Wolle, Freshw. Alg. of U. S., p. 181, tab. 161, fig. 1, tab. 162, fig. 2.

Cells single, spherical to ellipsoidal with relatively delicate membrane, parietal convexo-concave chromatophores with scarcely lobed margin and a central nucleus. On division are often formed 2-4-celled aggregates, in which case the chromatophores of the cells are mostly situated on the outside walls. Filamentous stages, which sometimes originate from such aggregates, are frequently formed. Sometimes these stages show distinct irregular branching. Chodat described also stages resembling *Dactylothece* and *Hormotila*. Whether to this belong cells mentioned by Chodat similar to *Trochiscia* is not certain. Resting stages observed by Pascher, in connection with vegetative stages are not similar to those described by Chodat. Usually yellowish green, the membrane is thickened, the outermost layer appears to be crenate due to wrinkles and irregular lobes. In some cases oil could be proved to be present. Chodat distinguishes a variety *quarternarium,* in which four-celled coups predominate. The size of the cells is 8-14μ (2-3μ rarely up to 25μ)Chodat also describes *Pleurococcus lobatus,* which is distinguished only by its chromatophores being more lobed and four-celled packets seem to be present in greater numbers. Pascher is unable to say how far *Pleurococcus lobatus* is identical with *Protococcus viridis* var. lobatus which in his later papers Chodat does not refer to.

Habitat.—Salt lakes near Calcutta, *see* Pl. VII, fig. 19.

This is the only subaerial alga that has been found in the Salt-lake region, growing abundantly on the trunks of *Avicennia officinalis, Excoecaria Agalocha*, and often also on the rhizophores of the plants of this region, especially on the portions which remain above the level of the water.

(*vi*) Family— CLADOPHORACEAE.

27. *Chaetomorpha Linum* (Muell.) Kuetz.

De Toni, Syll. Alg., Chl. vol. I, p. 269; Tab. Phyc. III, tab. 55. fig. 3; Chaetomorpha chlorotica Kuetz. Sp. Alg., p. 377; Tab.

Phyc. III, tab. 54, fig. 2; Chaetomorpha setacea Kuetz., Sp. Alg., p. 377; Tab. Phyc. III, tab. 54, fig. 3; Chaetomorpha rigida Kuetz. Sp. Alg., p. 377; Tab. Phyc. III, tab. 54, fig. 1; Rab. Fl. Eur. Alg. III, p. 328; Chaetomorpha brachyarthra Kuetz. Sp. Alg., p. 377; Tab. Phyc. III, tab. 53, fig. 4; Chaetomorpha dalmatica Kuetz. Sp. Alg., p. 378; Tab. Phyc. III, tab. 55; Chaetomorpha chlorotica Kuetz. Records of Bot. Surv. of India, vol. III, No. 2, p. 329.

Filaments floating freely in masses, loosely entangled, yellowish-green or deep dark-green, rigid, here and there curved, very elongated, 60-105μ (300μ) in width, cells 1-2 (rarely 4-5) times longer than broad, rarely shorter, cylindrical or ventricose.

Habitat.—Salt-lakes near Calcutta, *see* Pl. IX, fig. 22 (*a-c*).

Kuetzing has not mentioned any species in his Species Algarum of the name of *Chaetophora chlorotica*, neither any species under this name has been mentioned by De Toni in his Sylloge Algarum of the genus Chaetophora. But Kuetzing has described a species *Chaetomorpha chlorotica*, in his Sp. Alg., p. 577, which was later on described by De Toni in his Sylloge Algarum, Chlorophyceae, vol. I, p. 267, under the name of *Chaetomorpha Linum* (Muell.) Kuetz, which belongs to the family of Cladophoraceae. Therefore, the species *Chaetophora chlorotica* Kg. reported from the Salt-lakes by Sir D. Prain in the Records of the Botanical Survey of India, vol. III. No. 2, 329 is *Chaetomorpha chlorotica* of Kuetzing and therefore belongs to the family of Cladophoraceae and not to that of Chaetophoraceae.

28. *Rhizoclonium hieroglyphicum* (Ag.) Kuetz.

De Toni Syll. Alg., Chl, vol. I, p. 281 ; Kuetz. Sp. Alg., p. 385, No. 12 ; Rab. Fl. Eur. Alg. vol. III, p. 329 ; Hansg., Prodr. p. 78, No. 105; Rhizoclonium aponinum Kuetz., Tab. Phyc. III, Alg., p. 384 ; No. 7 ; Tab. Phyc. III, tab. 69, fig. 3 ; Rhizoclonium affine, Sp. Alg., p. 485, No. 14 ; Tab. Phyc. tab. 71, fig. 2 ; Rhizoclonium calidum, Tab. Phyc. tab. 70 fig. 3 ; Conferva Antillarum Kg. Sp. Alg., p. 372, No. 18; Tab. Phyc. tab. 45, fig. 2; Rab., Fl. Eur. Alg. III, p. 326; Record of the Bot. Surv. of India, vol. III, No. 2, pp. 329, 330.

Plant deep-green, or pale-green, losely entangled when dry, very much adhering to the sheets of paper; filaments with short lateral rhizoid-like processes protruding here and there; cells 12-25μ in width, 2-3 times as long as broad, not constricted at the joints.

This species was found by Sir D. Prain at Matla in brackish water and it is likely to occur also in the Salt-lakes. See Pl. X, fig. 23 (*a-c*).

(*vii*) Family—ULVACEAE.

29. *Enteromorpha prolifera* (Muell.) J. Ag.

De Toni, Syll. Alg. Chlor., vol. I, p. 122 ; Kuetz., Tab. Phyc. VI, tab, 30, fig. 3.

Plant mass yellowish-green, at first attached to the substratum, but later on floating freely in masses about 6 dm. long. The fronds are long, attenuated, tubulose, at first simple, but later densely branched, the smaller branches originating everywhere, more or less at an angle of 45°, and arranged acropetally. The ultimate branches contain a single row of cells, attenuated towards the end, obtusely rounded and very thin varying from 6-25μ in width, cells in comparatively younger branches are mostly uniformly rectangular, rarely oblong or hardly square and vary from 6-12u in length and 3-6μ in width. The apical cells of the ultimate branchlets are about 12μ long and 6μ board. The intermediate cells of the primary thallus are small, mostly rectangularly polyhedral, arranged in longitudinal series, surrounded by conspicuous hyaline walls, 7-24μ in length and 6-12μ in width; chromatophores yellowish-green, spherical, oblong or oval, close to the wall with empty spaces between them.

Habitat.—Salt-lakes, floating in masses; supposed to be a good food for fish, *see* Pl. VIII, fig. 20 (*a-g*).

30. *Enteromorpha intestinalis* (L) Link.

De Toni, Syll. Alg., Chl.; p. 123, Records of Bot. Survey of India, vol. III, No. 2, 239; Rab., Fl. Eur. Alg., vol. III,

p. 312; Kuetz. Sp. Alg., p. 478; Tab. Phyc. VI, tab. 31; Cooke. Brit. Freshw. Alg., p. 130, tab. 51, fig. 1-2; Wolle, Freshw. Algae U. S., p. 107, tab. 125, figs. 9-10; Hansg. Prodr., p. 55, N. 62, fig. 20-21.

Plants frequently floating on the surface of the water, more or less of the form of intestines, about 1-20 dm. long, 1-10 cm. broad, yellowish-green in colour and membranaceous; fronds elongated, attenuated towards the end, tubulose, cylindrical, clavate, often inflated bullose, simple or sparingly branched at the base, cells large, roundedly polyhedral, soon irregularly arranged towards the apex of the branch, elliptical-oblong on both sides or especially towards the interior, most of the intermediate layer of cells very firmly held together; the chromatophores more or less granular, those along the walls larger with empty spaces between them.

Salt-lakes near Calcutta, *see* Pl. IX, fig. 21 (*a-e*).

(*viii*) Family—Mougeotiaceae.

31. *Mougeotia affinis* Kuetz.

Keetz., Species Alg., p. 433; Rab. Fl. Eur. Alg., vol. III, p. 261; De Toni, Sylloge Alg., Chl., p. 724.

Cells 30μ in width, 3-5 times longer than broad.

This species is likely to occur in the Salt-lake region, as it has been mentioned by Sir D. Prain to occur in brackish water at Matla, which is close to the Salt-lakes. As a rule Conjugatae are very rare in these parts, but I have also found a species of Spirogyra growing very healthily forming large cushions of deep green slimy filaments in a depression filled with brackish water. This species of Spirogyra is now in culture.

III. Phaeophyceae.

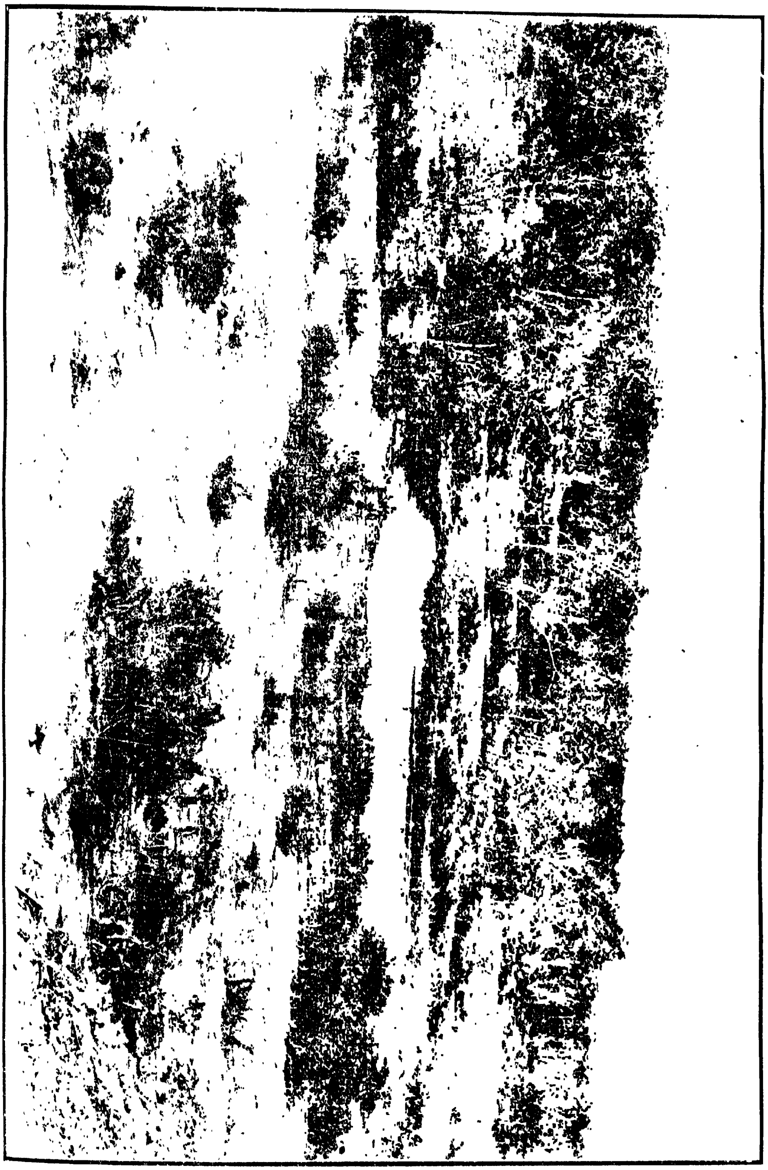
(*ix*) Family—Encoeliaceae.

32. *Encoelium vesicatum* Kuetz.

Spec. Alg., p. 552, No. 11; Records of the Bot. Surv. of India, vol. III, No. 2, p. 331.

PLATE V.

K. P. BISWAS—



General view of the plant formation on comparatively drier lands in the Salt-lake region.

The Thallus is membranaceous, leaf-like or polymorphous, sinuous with margins inflated or swollen.

Habitat.—Banks of Canals near Salt-lakes, Calcutta.

IV. Rhodophyceae.

(x) Family—Compsopogonaceae.

33. *Compsopogon lividus* (Hooker) De Toni.

De Toni Sylloge Alg., Florideae, vol. I, p. 28; Commentationes Algologicae, IV, pl. 1-3 in the Journal of the Dept. of Science, C. U., vol. VII; Compsopogon Hookerii Montagne. Records of the Bot. Surv. of India, vol. III, No. 2, p. 331.

Habitat.—Canal banks near Calcutta Salt-lakes, marshes at Matla.

I have not found this species in salt water or brackish water, but I collected specimens from fresh water pools and tanks at Baliganj.

(xi) Family—Rhodophyllidaceae.

34. *Catenella Opuntia* (Good. et Woodw.) Grev.

Kuetzing, Sp. Alg., p. 724; Records of the Bot. Surv. of India, vol. III, No. 2, p. 331; De Toni, Sylloge. Alg., Florideae, vol. I, pp. 318, 319.

Fronds when young, procumbent and creeping, forming cushions, constricted at the joints, dichotomous or trichotomous; cells compressed ellipsoidal or often obovate, mostly 3-5 times longer than the diameter.

Habitat.—Salt-lakes near Calcutta; banks of river Hughly.

(xii) Family—Delesseriaceae.

35. *Caloglossa Leprieurii* J. Ag.

Kuetz., Sp. Alg., p. 875; Tab. Phyc. XVI, t. 10; De Toni, Sylloge Alg. Florideae, vol. II, p. 729; Records of the Bot. Survey of India, vol. III, No. 2, p. 331..

Fronds violet, ribbon-like, dichotomous, each segment of the ribbon is lanceolate, linear, attenuated at both ends, more or less articulate, constricted, radiating; cells oblong—lanceolate, growing out symmetrically.

Habitat.—Salt-lakes near Calcutta; Kidderpore on walls covered at high tide. *See* Pl. X, fig. 24 (*a-c*).

36. *Hypoglossum Pygmaeum* Mart.

De Toni, Sylloge Alg., Florideae, vol. II, p. 695; Alg. Bengal N. 3039, J. Ag. Eper., p. 468; Delessaria pygmace (Martens) Prain. Fl. of 24-Perganas, in the Records of the Bot. Surv. of India, vol. III, No. 2, p. 331.

(*xiii*) Family—RHODEMELACEAE.

37. *Polysiphon Brodiacae* (Dillw.) Grev.

De Toni, Sylloge Alg., Florideae, pp. 947-49; Kuetz, Sp. Alg., p. 827; Tab. Phyc. XIV, tab. 1, fig. d-f; Polysiphon pericillata Kuetz, Sp. Alg. p. 827; Tab. Phyc. XIV., tal. 2, fig. e-g; Polysiphon Polychotoma Kuetz., Sp. Alg., p. 827; Tab. Phyc. XIV., tab. 2, fig. e-g; Polysiphonia Polychroma Mert., Records of the Bot. Survey of India, vol. III, No. 2, p. 331.

Fronds pyramidal, feather-like, with the branches decomposed, branches elongated and corticated, smaller branches ovate with penicillate fascicles at the end, having some of the feather-like decomposed branches projecting out in sharply pointed ends; cells with 6-8 tubes twice as long as the diameter of the branches almost equal to their diameter; the tubes arranged in a series around the centre, the smaller ones separated from the centre; tetrasporangia moniliform on smaller branches; cystocarps ovate and stalked.

Habitat.—Salt-lakes, Calcutta, *see* Pl. X, fig. 25 (*a-e*).

De Toni in his Sylloge Alg. does not mention any species called *Polysiphon polychroma* Martens reported by Sir David Prain in the Records of Bot. Surv. of India, vol. III, No. 2, p. 331 from the Salt-lakes. Kuetzing however has described a species of the name of *Polysiphon Polychotoma*, which has been included by De Toni in his Sylloge Alg., Florideae, p. 947, in the species *Polysiphon Broadiaei* (Dillw.) Grev. It is therefore quite evident that *Polysiphon Polrchroma* of Marten is probably the same as *Polysiphon Polychotoma* of Kuetzing which is the same as *Polysiphon Drodiaei.*

38. *Polysiphon angustissima* Kuetz.

De Toni, p. 960, Sylloge Alg., Florideae, vol. III, p. 960; Polysiphon Ophiocarpa Kuetz. Sp. Alg., p. 810, No. 55 ; Tab. Phyc. XIV, p. 17, tab. 47, fig. d-g ; Records of the Bot. Surv. of India vol. III, No. 2, p. 331.

Fronds bristle-like, root-like at the base, branching like a twig, erect, rigid, all the fruiting bodies deposited longitudinally on the thallus, erect, adpressed, loosely racemose, elongated, the largest ones curved and flexuous, penicillate at the apex: cells composed of 18-20 tubes, lower primary ones twice, sometimes three times shorter than the diameter; the upper ones short equal to the diameter or cylindrical.

Habitat.—Salt-lakes, Calcutta, *see* Pl. X fig. 26 (*a-d*).

39. *Bostrychia rivularis* Harv.

De Toni, Sylloge Alg., Florideae, vol. III, p. 1157 ; Records of the Bot. Surv. of India vol. III, No. 2, p. 332.

Fronds diffuse, feather-like, with branches decomposed, articulated throughout, branches coming out in two rows or arranged distichously, the terminal ones, erect, sub-corymbose, and curved inwards; the lower ones more or less horizontal, furcate or somewhat feather-like, with smaller branches growing all over up to the apex, composed of many tubes; cystocarps ovate, situated on the transformed terminal branchlets; cells in the

primary branches containing 6-8 tubes slightly shorter than the diameter.

Habitat.—Salt-lakes near Calcutta.

(*xiv*) Family—CERAMIACEAE.

40. *Ceramium gracillimum* Griff. et Harv.

De Toni, Sylloge Alg., Flor., p. 1483; Hormoceras flaccidum Agardh, Records of the Bot. Surv. of India, vol. III, No. 2, p. 332; Homoceras flaccidum Harvey in Kuetz. Tab. Phyc. XII, tab. 68.

Fronds very small and fine, withered, with very small lateral dichotomous dissimilar branchlets seated on them; the branchlets dichotomously pointed like forceps, the lower cells 5-6 times longer than broad, in branchlets almost equal to their diameter, at the joints marked by a zone of cortical stratum; tetrasporangia more or less in a whorl, towards the upper part protruding and naked, but in the lower part girdled by a cortical layer of cells, cystocarps situated towards the apex of the branchlets; the branchlets arranged in an involucre, elongated fork-like with many prongs, appearing like an open umbrella.

Habitat.—Salt-lakes near Calcutta, *see* Pl. X, fig. 27 (*a-d*).

Harvey and not Agardh is the author of *Hormoceras flaccidum* Harv., which is included by De Toni in *Ceramium gracillimum* Griff. et Harv.

FERNS.

Family—POLYPODIACEAE.

I. *Acrostichum palustre* Bedd.

B.P., p. 1260; Fl. of 24 Perg., p. 325.

2. *Acrostichum aureum* Linn.

B.P., p. 1261; Fl. of 24 Perg., p. 325.

List of Phanerogamic Plants.

MONOCOTYLEDONS.

(i) Family—POTAMOGETONACEAE.

1. *Potamogeton pectinatus* Linn.

B. P., ii, p. 1123; Fl. of 24 Perg., p. 298.

2. *Ruppia rostellata* Koch.

B. P., ii, p. 1124; Fl. of 24 Perg., p. 298; F. I., vol. VI, 568; F. S. B. P., p. 349.

(ii) Family—GRAMINACEAE.

3. *Phragmites Karka* Trin.

Fl. of Sundriban, p. 360; B. P., ii, p. 1209; Fl. of 24 Perg. p. 320; F. B. I., vol. VII, p. 305; Fl. I., i, p. 348.

4. *Myriostachya Wightiana* Hook. f.

Fl. of 24 Perg., p. 321; F. B. I., vol. VII, p. 327, Fl. of Sundriban, p. 360.

5. *Cynodon dactylon Pergs.*

H. S., 721 B. P., ii, p. 1227; Fl. of 24 Perg., p. 322.

6. *Zoysia pungens* Willd.

H. S., 709, B. P., ii, p. 1186; F. B. I., vol. VII, p. 99.

(iii) Family—CYPERACEAE.

7. *Fimbristylis ferruginea* Vahl.

H. S., 725, B. P., ii, p. 1154 ; F. B. I., vi, p. 638

DICOTYLEDONS.

(i) Family—*Chernopodiaceae.*

1. *Suaeda maritima* Dumort.

Fl. of 24 Perg., p. 267; F. B. I., vol. V, p. 15 ; F. I., ii, p. 62; Flora of Sundriban, p. 533; Bengal Pl., p. 878.

(*ii*) Family—AMARANTACEAE.

2. *Alternanthera sessilis R.* Br.

Fl. of 24 Perg., p. 267; F. B. I., vol. IV, 731; F. I. i, p. 678; Bengal Pl., p. 875; Fl. of Sundriban, p. 333.

(*iii*) Family—DROSERACEAE.

3. *Aldrovanda vesiculosa* Linn.

Fl. of 24 Perg., p. 210; F. B. I., vol. II, p. 425; F. I., ii, p. 112; Fl. of Sundriban, p. 305; Bengal Pl., p. 472. A Manual of Indian Botany, by G. C. Bose, M.A., pp. 66, 67.

(*iv*) Family—LEGUMINOSEAE.

4. *Sesbania paludosa* Prain.

B. P., p. 404; Aeschynomene paludosa Hs., p. 219; Fl. of 24 Perg., p. 199.

(*v*) Family—EUPHORBIACEAE.

5. *Euphorbia antiquorum* Linn.

B. P., p. 923; Fl. of 24 Perg., p. 271.

6. *Agyneia bacciformis* A. Juss.

B. P., ii, p. 923; F. B. I. V. 285; Phyllanthus bacciformis, F. I., iii, p. 661.

7. *Excoecaria Agalocha* Linn.

Fl. 24 Perg., 278 ; B.P., p. 955; F. B. I., vol. V, p. 472 ; F. I. iii, p. 956 ; Fl. of Sundriban, p. 339.

(*vi*) Family—TAMARICACEAE.

8. *Tamarix gallica* Linn, *var. indica* Dyer.

B. P., p. 242; Fl. of 24 Perg., p. 176; F. B. I., p. 248; F. I., p. 100; Fl. of Sundriban, p. 287.

(*vii*) Family—LYTHRACEAE.

9. *Sonneratia apetala* Ham.

B.P. p. 505 ; F. B. I., vol. II, p. 679 ; Fl. of 24 Perg., p. 214; Fl. of Sundriban, p. 309; F. I., ii, p. 506.

(*viii*) Family—RHIZOPHORACEAE.

10. *Ceriops Roxburghiana* Arn.

B. P., p. 476 ; Fl. of 24 Perg. 211 ; Fl. of Sundriban, p. 306 ; F. B. I., vol. II, p. 436.

11. *Kandelia Rheedei* W. & A.

B. P., p. 476 ; Fl. of 24 Perg., p. 211 ; Fl. of Sundriban, p. 306 ; F. B. I., vol. II, p. 437.

(*ix*) Family—MYRSINACEAE.

12. *Aegiceras majus* Gaertn.

B. P. I., p. 645 ; Fl. 24 Perg., p. 233 ; F. B. I., vol. III, p. 533; F. I., iii, p. 180; Fl. of Sundriban, p. 316.

(*x*) Family—ASCLEPIADACEAE.

13. *Calotropis gigantea* R. Br.

B. P., p. 688 ; Fl. 24 Perg., p. 238 ; F. B. I. vol. IV, p. 17 ; F. I., ii, p. 30 ; Fl. of Sundriban, p. 318.

14. *Pentatropis microphylla* W. & A.

B.P., p. 691 ; Fl. of 24 Perg., p. 238 ; F. I. ii. p. 35 ; F.B.I. Vol. IV, p. 20 ; Fl. of Sundriban, p. 319.

15. *Tolyphora tenuis* Bl.

B.P., ii, p. 698 ; Fl. 24 Perg., p. 239 ; F. B. I., vol. IV., p. 42 ; F. I., ii, p. 41.

(*xi*) Family—CONVOLVULACEAE.

16. *Cressa cretica* Linn.

B. P., ii, p. 725 ; Fl. 24 Perg., p. 243.

17. *Stictocardia tiliæfolia Hallier f.*

B. P., ii, p. 740 ; Fl. 24 Perg., p. 246 ; F. B. I., vol. IV, p. 184 ; F. I., i, p. 467 ; Fl. of Sundriban, p. 322.

(*xii*) Family—BORAGINACEAE.

18. *Heliotropium curassavicum* Linn.

Recently introduced in Bengal and reported for the first time from India.

(*xiii*) Family—ACANTHACEAE.

19. *Acanthus ilicifolius* Linn.

B. P., p. 800 ; Fl. of 24 Perg., p. 256 ; F. I., iii, p. 32 ; F. B. I., vol. IV, p. 481 ; Fl. of Sundriban, p. 327.

(*xiv*) Family—VERBENACEAE.

20. *Clerodendron inerme* Gaertn.

B. P., p. 835, Fl. of 24 Perg., p. 261, F. B. I., vol. IV, p. 589, F. I., iii, p. 58, Fl. of Sundriban, p. 330.

21. *Avicennia officinalis* Linn.

B. P., ii, p. 838; Fl. of 24 Perg., p. 261.

Economic Importance.

Very few plants of the Salt-lake region are of economic importance; most of the woody plants are used for fuel. The juice of *Excoecaria Agalocha* is suposed to be poisonous and the wood is used in the manufacture of match sticks. *Ceriops Roxburghiana* yields a good tanning material and is much used for making huts and thatches. The medicinal properties of *Calotropis gigantea* are well known and the fruits of *Sonneratia apetala* are eaten by local people.

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PLATE VI.

K. P. BISWAS —

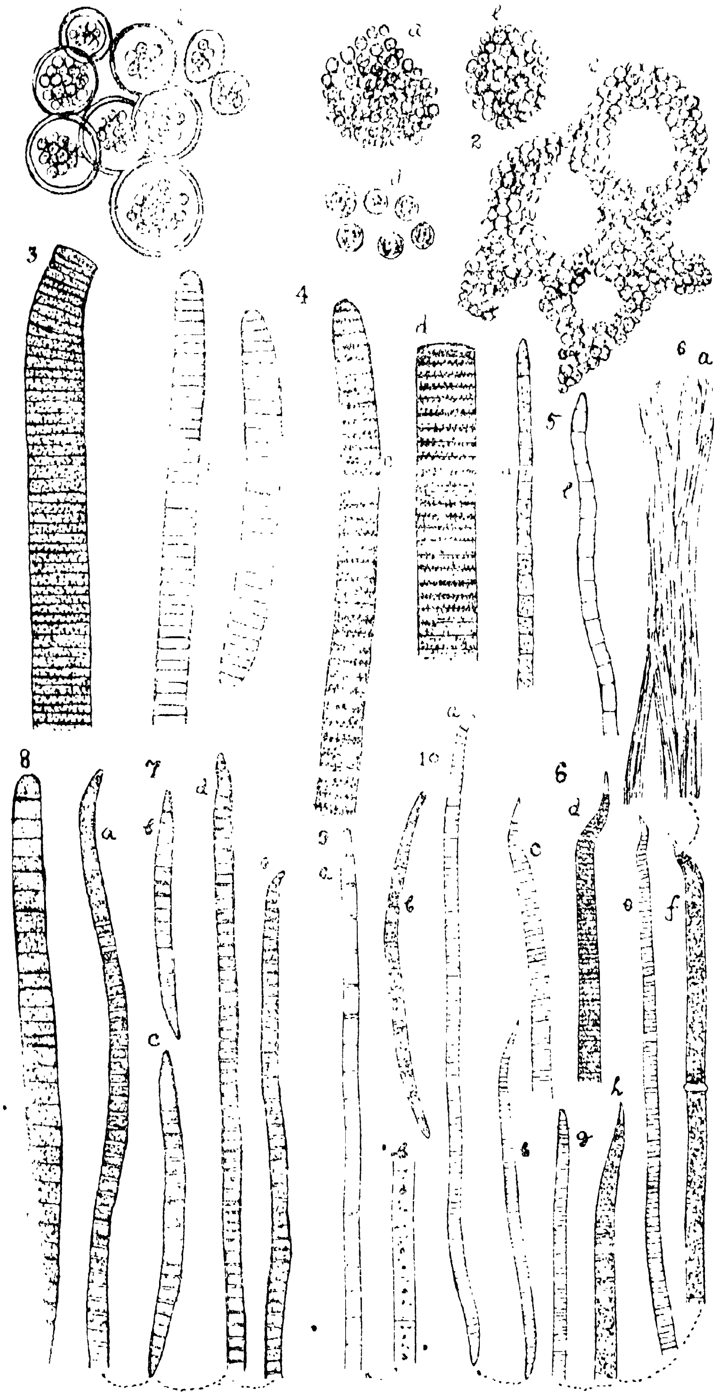


PLATE VII.

K. P. BISWAS—

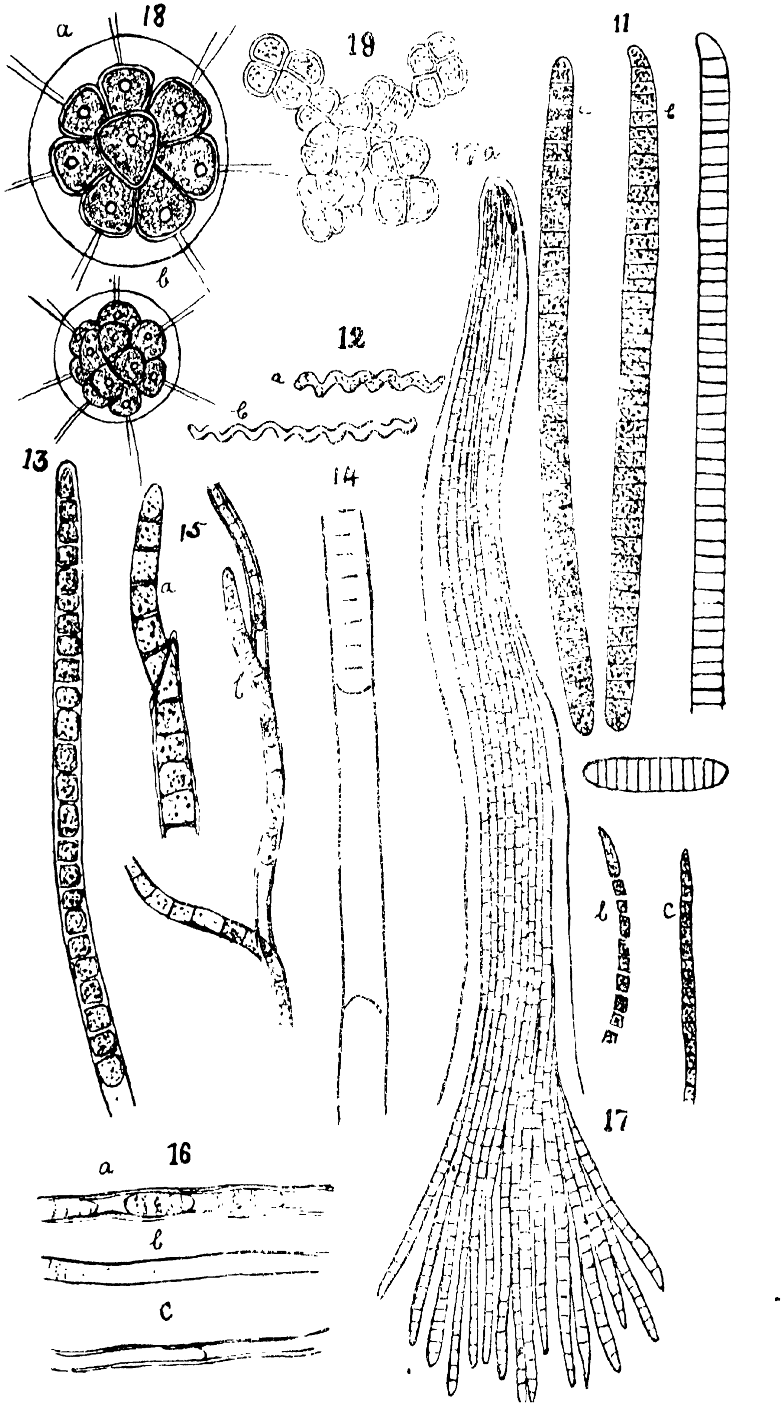


PLATE VIII.

K. P. BISWAS—

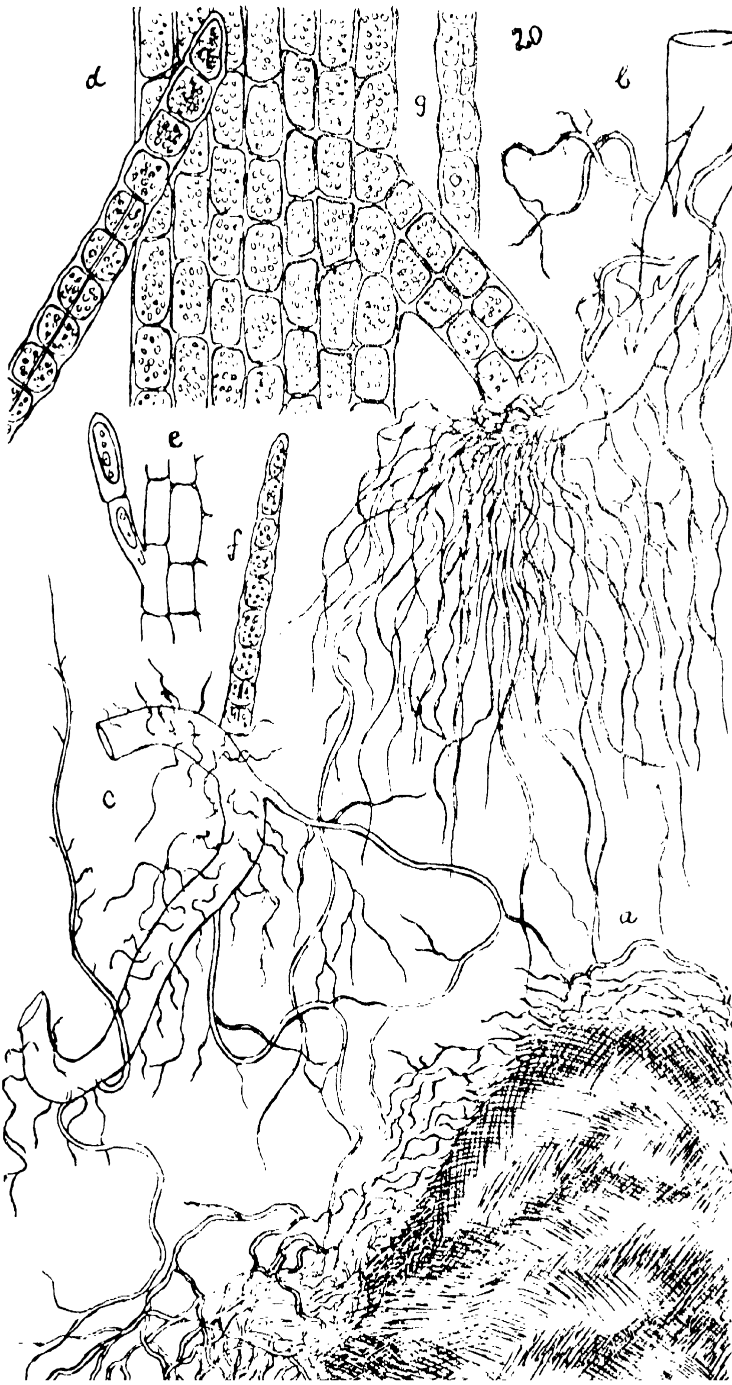
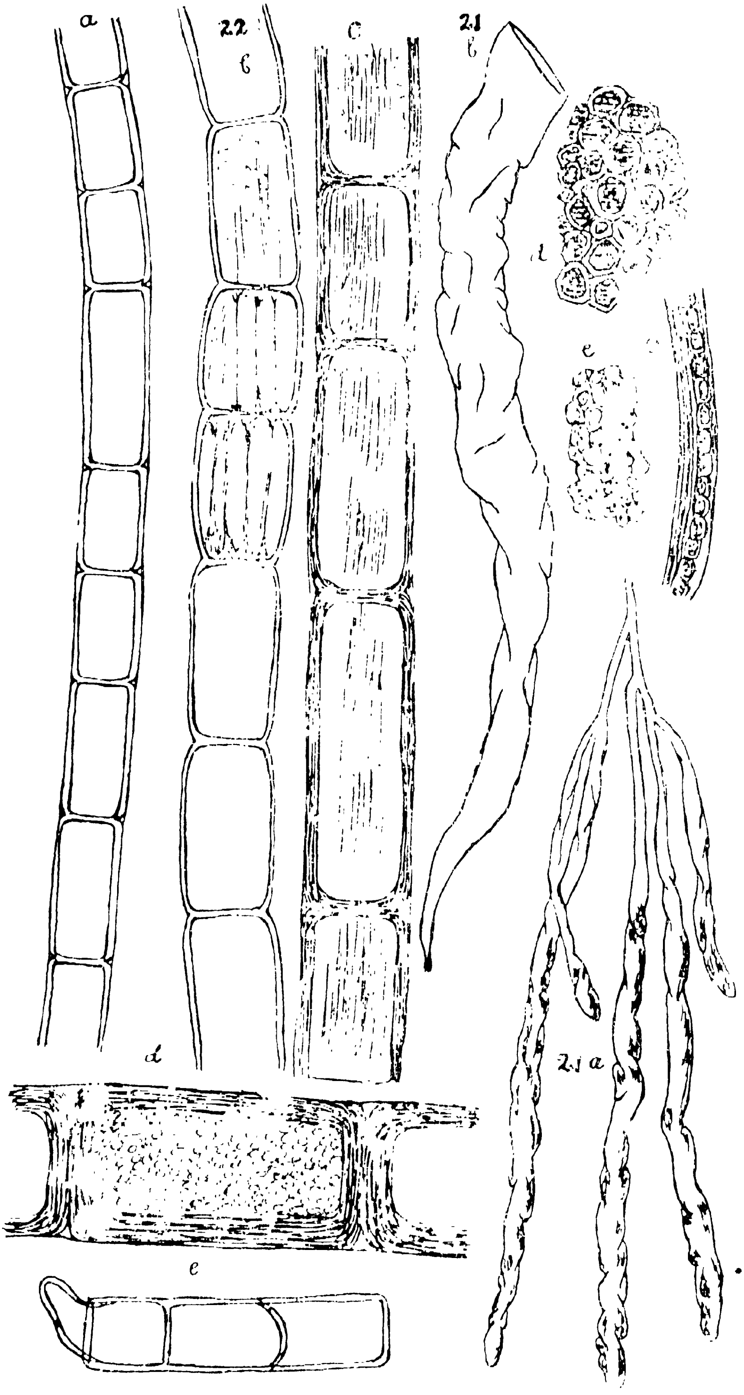


PLATE IX.

K. P. BISWAS—



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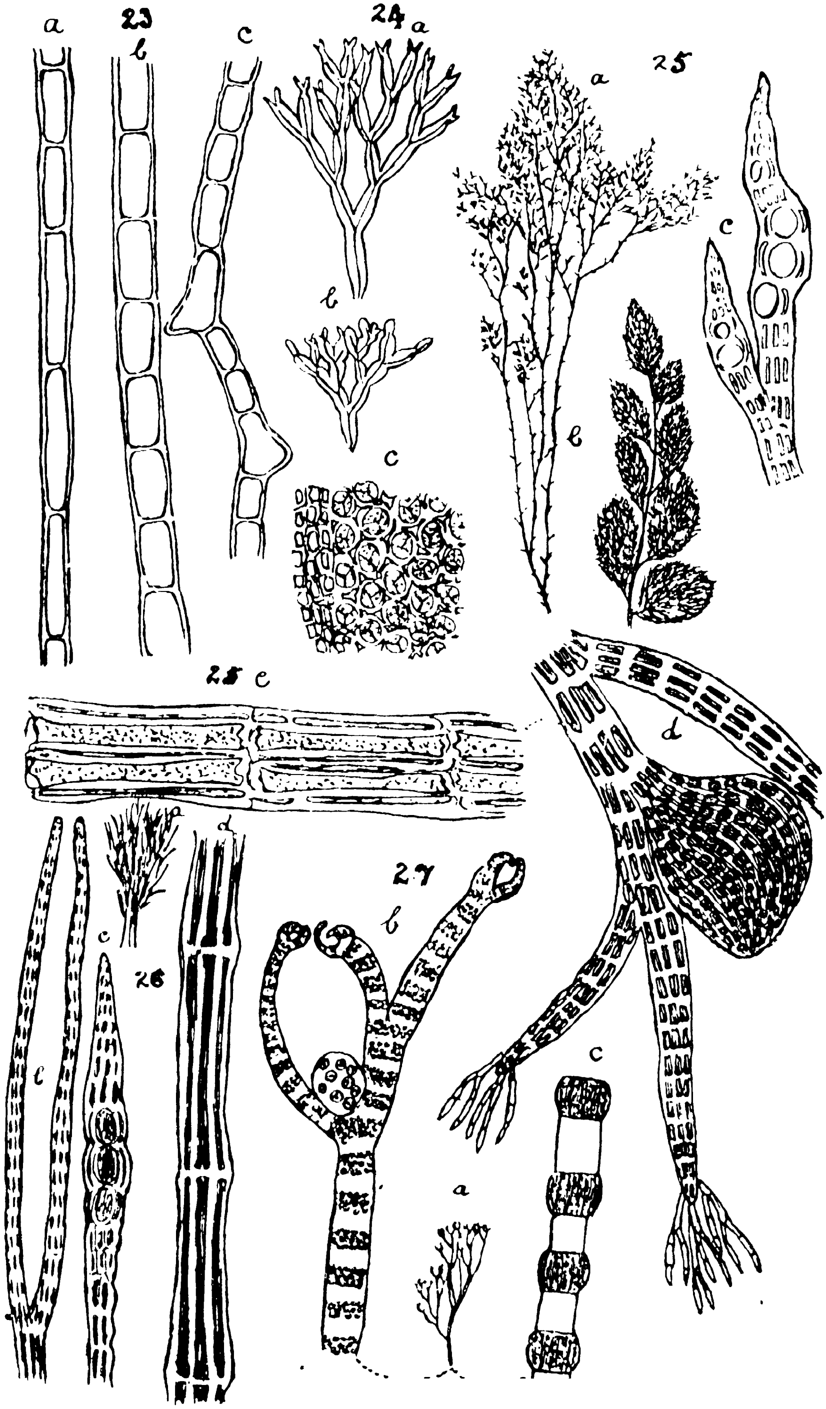

Aquatic Vegetation of Bengal in Relation to supply of Oxygen to the Water.

BY

KALIPADA BISWAS.

The aquatic vegetation of Bengal plays a very important part in the biology of lakes, pools, tanks and other reservoirs of water. The main point of importance lies in the supply of pure oxygen to the water. The oxygen supplied to the water is the result of assimilation of the plants living in the water. The macroplankton flora, most of which floats on the surface with their roots remaining under water, such as: *Ipomaea reptans*, *Jussiaea repens*, *Lemna paucicostata*, *Lemna polyrrhiza*, *Lemna trisculа*, *Lemna oligorrhiza*, *Wolffia arrhiza*, *Wolffia microscopica*, *Pistia Stratiotes*, *Leersia hexandra*, *Hygroryza aristata*, *Coix aquatica*, *Eichhornia speciosa*, *Ceratopteris thalictroides*, *Salvinia cucullata*, *Azolla pinnata* and *Marsilea quadrifolia*, is indirectly helpful in supplying oxygen to the water of lakes, tanks and pools. A considerable amount of oxygen given out by those plants is absorbed by the surface film of the water, as the pure oxygen, heavier as it is than the atmosphere, rests for sometime immediately above the water. Also the amount of absorption of a gas by a liquid depends on the partial vapour pressure which the gas exerts on the surface of the liquid; thus the partial vapour pressure of the oxygen, being increased in consequence of its exhalation by the aquatic plants, a larger portion of the oxygen is absorbed by the water than would be absorbed in ordinary conditions. But on the other hand the macroplankton flora must not be sufficiently dense completely to cover the surface of the water and thus prevent the layer of oxygen from being absorbed

by the water, as it often happens by the abundant growth of *Eichhornia speciosa, Pistia Stratiotes,* species of *Lemna, Salvinia cucullata* or *Azolla pinnata* either constituting a pure or frequently mixed formation and thus choking up entirely the surface of the water. Again, those plants, as for example, *Nymyhaea Lotus, Nymphaea rubra, Nymphaea stellata, Nelumbium speciosum, Limnanthemum cristatum, Limnanthemum indicum, Trapa bispinosa* and species of *Aponogeton* and *Potamogeton*, which are rooted at the bottom of the lakes, tanks and pools supply a larger amount of oxygen through the stomatic pores of their leaves floating on the surface of the water.

The major portion of oxygen present in the lakes, tanks and pools is supplied mainly by submerged vegetation, which sometimes reaches a considerable depth. According to Schimper, six metres is the maximum depth suitable for phanerogams, but Chara and Nitella have been found to grow even at a depth of thirty metres.

Though a detailed ecological classification of the aquatic vegetation of Bengal has not yet been worked out, yet we can roughly distinguish four zones: first, the bottom zone chiefly with blue-green algæ and diatoms as well as resting spores of other algæ and flagellata; secondly, a zone of phanerogamic plants rooted at the bottom forming more or less an aquatic meadow; thirdly, an intermediate zone of algæ and submerged floating species of phanerogamic plants; and fourthly, a surface stratum of pure macroplankton or microplankton or a mixture of the two.

The plants of the first zone lie mostly on the bottom mud and are not very important from the standpoint of supplying oxygen to the water, but they appear to check the growth of putrifaction bacteria. This bottom layer is also responsible for the growth of hydrophytes as a whole by harbouring winterbuds, seeds and spores of aquatic plants.

The second zone which chiefly consists of plants submerged in the water, but rooted at the bottom forming a sort of meadow of either individual species or a combination of several species of submerged plants. When it forms a group of only one species, such as *Vallisneria* or *Potamogeton*, it may be called *Vallisnerietum* or *Potamogetonetum.* The common species belonging to this layer are: *Vallisneria spiralis, Hydrilla verticillata, Lagarosiphon Roxburghii, Blyxa Roxburghii,*

Ottelia alismoides, Aponogeton monostachyus, Aponogeton crispus, Potamogeton indicus, Potamogeton crispus, Potamogeton pectinatus, Najas indica, Najas foveolata, Najas minor, Najas graminea, Eleocharis spiralis, species of *Chara, Nitella* and others.

The third zone which gradually merges into the top layer of the water is chiefly composed of algae either floating or epiphytic which are very active in giving out a quantity of oxygen to the water. The phanerogamic plants found in this Intermediate Zone are: *Utricularia stellaris, Utricularia flexuosa, Utricularia exoleta, Utricularia reticulata, Utricularia racemosa, Utricularia bifida,* detached portions of *Ceratophyllum demersum* and *Hydrilla verticillata.*

The macroplankton and microplankton floras which form the Surface Zone undoubtedly perform their share in supplying oxygen to the water and at the same time purifying the water. The common microplankton flora of Bengal lakes, tanks, pools and khals consists of blue-green algae the chief of which are *Clathrocystis aeruginosa, Clathrocystis robusta, Anabaena flos-aquae* var. *circinalis, Anabaena sphaerica, Cylindrospermum doryphorum, Arthospira platensis* and a few species of *Oscillatoria.*. Of these *Clathrocystis aeruginosa* is the predominant species. Green algae forming a constituent of the plankton flora are also not very uncommon and sometimes *Volvox aureus* forms a pure formation. *Scenedesmus quadricauda, Gonium pectorale, Pediastrum duplex* var. *genuinum, Pediastrum tetras, Pediastrum clatrata, Ankistrodesmus falcatus, Chlorella vulgaris, Pandorina Morum, Euglena* sp, species of desmids and diatoms are frequently found among plankton algae besides filamentous species, such as *Trebonema bombycinum, Ulothrix* sp, *Chaetomorpha Linum, Stigeoclonium* sp, species of *Enteromorpha* (in the Salt-Lakes) and others. Members of the macroplankton flora have already been mentioned. Some of the species of plankton algae are very useful in the self-purification of water and the actual process has been summed up in the following lines of my paper on "The Algal Flora of the Maidan Tanks":

"The self-purifying operation is chiefly performed by microscopic animals and plants after sedimentation of coarser impurities. The first to get hold of the impurities are putrifaction bacteria, the action of which results in the production of ammonia, acetic acid, sulphuretted hydrogen, peptone and various other organic compounds of complicated

structure. These compounds are assimilated by plankton algae and other members of the plant kingdom. As soon as these have consumed the obnoxious substances, they are swallowed by small members of the animal kingdom which in their turn serve as food to larger crustaceans and fishes. It may, however, happen that ponds and rivers are so overloaded with refuse matter that the sanitary agents referred to above are unable to fulfil their obligations and that in consequence of this state of things sulphur bacteria, Oscillatorias and certain infusoria gain the upper hand. Some of these occur so constantly in contaminated waters that they can be used as indicators, the presence of which is a sure proof of the insanitary state of the water which has been subjected to microscopic investigation. In the process of self-purification the oxygen exhausted by algae plays an important part."

The oxygen supplied to the water of lakes, tanks, ponds and khals in our country is a most important factor in pisciculture.

The animals and plants must have sufficient oxygen for their respiration ; in the flowing water of rivers and streams and also in the water of larger lakes, such as the Chilka Lake, the salt-lakes at Ennore, Madras, the Calcutta salt-lakes, there is a sufficient amount of oxygen dissolved in the water for aquatic organisms to breathe. But conditions are different in the stagnant waters of tanks, pools and smaller lakes. "It is in such places that organic debris tends to accumulate, and, in decay, overcharges the water with the gases of decomposition, especially that of carbon dioxid. Of course, whatever animal life is present under such conditions still further reduces the oxygen supply and increases the carbon dioxid. The green plants on the other hand during sunlight are constantly using the carbon dioxid for making starch and giving off oxygen as a waste product of the process. In this process the volume of oxygen released equals the volume of carbon dioxid used, so that an aquatic meadow, growing vigorously in a still water cove, would be very efficient in keeping the water well aerated and much to the advantage of all the animal life finding food and shelter there."—(Raymond H. Pond).

Moreover, algae which are epiphytic on the leaves of submerged plants and also some of the algae floating in the water are useful in supplying food and shelter to many invertebrates.

The aquatic meadow again acts as a filtering zone of suspended particles settling at the bottom which again is utilised by micro-

organisms lying below. Some of the larger algae are supposed to be favourite food of fishes. In addition to the supply of oxygen by the aquatic vegetation a good deal of oxygen can be artificially supplied to the water by the process of netting as practised by fishermen or by occasional agitation of the water of the tanks, pools and lakes, as suggested by Major R. B. Seymour Sewell, Director of the Zoological Survey of India, Indian Museum. This latter procedure would be one of the measures to prevent the mortality of fishes in our tanks, as pointed out by Major Sewell in his recent paper on "Investigations regarding an Epidemic of Fish Mortality in the Tank in the Indian Museum Compound," read at the monthly meeting of the Asiatic Society of Bengal, on the 5th July, 1926.

The bulk of the fresh water plants of Bengal are algae and phanerogams. Bryophytes and Pteridophytes are very rare.

A list of plants excluding algae, which are effective in supplying oxygen to the water is given below. The algae will be dealt with in detail in a separate paper.

I beg to record my indebtedness to Dr. P. Brühl, the University Professor of Botany, for his valuable suggestions in preparing this paper.

List of aquatic plants of Bengal in relation to supply of oxygen to the water. The plants are classified according to Engler's Syllabus der Pflanzenfamilien (1908).

A. Pteridophyta.

Family I. Parkeriaceæ.

1. *Ceratopteris thalictroides* Brogn.

Family II. Marsileaceæ.

2. *Marsilea quadrifolia* Linn.
3. *Marsilea minuta* Linn.

Family III. Salviniaceæ.

4. *Salvinia cucullata* Roxb.
5. *Azolla pinnata.* R. Br.

B. ANGIOSPERMÆ.

(i) *Monocotyledoneæ*

Family IV. Potamogetonaceæ.

6. *Potamogeton indicus* Roxb.
7. *P. crispus* Linn.
8. *P. pectinatus* Linn.
9. *Ruppia rostellata* Koch.

Family V. Najadaceæ.

10. *Najas indica* Cham.
11. *N. minor* All.
12. *N. foveolata* A. Br.
13. *N. graminea* Del.

Family VI. Aponogetonaceæ.

14. *Aponogeton monostachyus* Linn.
15. *A. echinatus* Roxb.
16. *A. crispus* Thumb.

Family VII. Alismataceae.

17. *Sagittaria guayanensis* H. B.
18. *Alisma renifarme* Don.
19. *A. oligococcum* F. Muell.
20. *Limnophyton obtusifolium* Mig.

Family VIII. Hydrocharitaceae.

21. *Ottelia alismoides* Pers.
22. *Hydrocharis cellulosa* Ham.
23. *Blyxa Roxburghü* Rich.
24. *Vallisneria spiralis* Linn.
25. *Lagarosiphon Roxburghii* Benth.
26. *Hydrilla verticillata* Casp.

Family IX. Graminaceae.

27. *Chamaeraphis spinescens* R. Br.
28. *C. gracilis* Hook. F.
29. *Leersia hexandra* S. W.
30. *Hygrorhiza aristata* Nees.
31. *Coix aquatica* Roxb.

Family X. Cyperaceae.

32. *Eleocharis plantaginea* R. Br.
33. *E. fistulosa* Schult.
34. *E. spiralis* R. Br.
35. *E. capitata* R. Br.
36. *E. palustris* R. Br.

Family XI. Lemnaceae.

37. *Lemna paucicostata* Heglen.
38. *L. trisculа* Linn.
39. *L. polyrrhiza* Linn.
40. *L. oligorrhiza* Kurz.
41. *Wolffia arrhiza* Winn.
42. *W. microscopica* Kurz.

Family XII. Pontederiaceae.

43. *Eichhornia speciosa* Kunth.

(*ii*) Dicotyledoneae.

Family XIII. Nymphaeceae.

44. *Nymphaea Lotus* Linn.
45. *N. rubra* Roxb.
46. *N. stellata* Wild.
47. *Nelumbium speciosum* Wild.

Family XIV. Ceratophyllaceae.

48. *Ceratophyllum demersum* Linn.
49. *Ceratophyllum* sp.

Family XV. Oenotheraceae.

50. *Trapa bispinosa* Roxb.
51. *Jussieua repens* Linn.

Family XVI. Gentianaceae.

52. *Limnanthemum cristatum* Griseb.
53. *L. indicum* Thw.

Family XVII. Convolvulaceae.

54. *Ipomoea reptans* Poir.

Family XVIII. Lentibulariaceae.

55. *Utricularia stellaris* Linn.
56. *U. flexuosa* Vahl.
57. *U. exoleta* R. Br.
58. *U. reticulata* S. W.
59. *U. racemosa* Wall.
60. *U. bifida* Linn.

University College of Science,
Botanical Laboratory.
Dated the 23rd September, 1926.

Aeroplane Motion.

Its Theory and Application.

BY

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PREFACE.

The following work is based on a presentation of actual facts which is a mathematical deduction of the "Grenzschicht" theory of Prof. L. Prandtl of the University of Göttingen. The only merit of the presentation lies in the fact that the results I have calculated in the following pages have been up till now at least in two cases, pages 77 and 92, verified and found to tally wonderfully well with experiments. Parts of the following work have already been published in the Philosophical Magazine, London, and Die Zeitschrift für angewandte Mathematik und Mechanik, Berlin. But I have included them in what follows to make it connected and complete; only the fact of secrecy which the competition entails debars me from giving more exact references to them. So much has to be taken on trust, and I believe the bona fides of the claims that I have made in the following pages will not be doubted. They can be verified if challenged.

A connection between the following parts of the work will be at once apparent. A theory has been deduced from some well-known experimental observations carried out during recent years by Prandtl, Eifel and a host of others. From these series of experiments a fact has been established and given a perfect shape by Prandtl's "Gränzschichttheorie." This theory of lifting-line having been established, I have deduced a series of relations for monoplanes and biplanes that lend themselves easily to experimental verification and that are of great use, due to their simplicity and exactness, to theoretical aerodynamics. Up till now verifications have only been possible in a few cases and references have been made to them in the body of the work.

A most important verification of one of the most important of relations is given in a separate chapter. I hope this will convince any one as to the bona fides of the other assertions, A list of literature, references and of certain technical terms is also appended.

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DEFINITION OF A FEW AERODYNAMICAL TERMS.

Angle of Attack—the acute angle between the direction of the relative wind and the chord of an aerofoil.

Aspect-ratio, S.—The ratio of span to chord of an aerofoil.

Biplane—A form of airplane in which the main supporting surface is divided into two parts, one above the other.

Décalage—An increase in the angular setting of the chord of an upper wing of a biplane with reference to the chord of the lower wing.

Drag-coefficient, C_w—that portion of the Drag of a wing which varies with its angle. $W = C_w \, . \, F.q.$, where $q = \frac{1}{2}\rho v^2$.

Lift-coefficient, C_a—is that portion of the Lift of a wing which varies with its angle. $A = C_a . \, F. \, q.$

Moment-coefficient, C_m—If a moment of all the forces on a wing be taken about its entering edge, then $M = C_m . \, t. \, F. \, q.$

Monoplane—A form of airplane whose main supporting surface is disposed as a single wing on each side of the body.

Stagger—The amount of advance of the entering edge of the upper wing of a biplane over that of the lower; it is considered positive, when the upper surface is forward.

INTRODUCTION.

Aerodynamics, even at the present day, is more a tentative science than an exact one. In it, as in every other applied science, every theory has to justify itself by the facts it can explain. During the last twenty years intensive work has been carried on in this line in Europe and America, and attention has been focussed on it due to the increased importance attributed to artificial flights now-a-days. But from the days of the classical theory to the present day Hydrodynamics has changed its character from a merely theoretical to a practical science.

According to the classical theory of Hydrodynamics we are told that if a solid body is completely immersed in a flowing fluid so that its boundaries do not reach the boundaries of the fluid, that is to say, if the fluid round it forms a singly-connected space, then the solid experiences no forces due to the even flow of the fluid. But if the space surrounding the body be doubly-connected, that is to say, if the limits of the fluid be touched by the boundaries of the body, then Kuta and Jonkowsky showed independently of each other what was foreshadowed by Lanchester, that the body experiences a force which acts perpendicularly to the direction of the free stream. In fact, the double-connectivity of the region round the body gave them the opportunity of introducing a suitable circulation about the body which was found to give the required lift. When we want to transfer this circulatory motion on to a body completely immersed in the fluid, we find the double-connectivity of the space wanting and ourselves incapable of applying the Kuta-Jonkowsky conception to singly connected space.

This incapacity, it was thought, would be removed by the Stokes and de Saint Venant Equations of viscous motion. But the results calculated from these equations of motion were found only to hold in those cases, where velocity is small and viscosity great. In the other

case, when viscosity was small and velocity appreciably great, calculations failed. Then Helmholtz came with his theory of Discontinuous Motion which, though strenuously opposed by theoretical Physicists, such as Kelvin and Tate, was a close approximation to actual facts. Helmholtz' Theory of Discontinuous Motion gave an expression for the fluid thrust which falls far short of experimental ones. If we compare the value of the thrust on unit length of a finite plane of breadth

$$T=\rho\pi \frac{t \sin \alpha}{4+\pi \sin \alpha} v^2$$

with those found by experiments on a plate of small aspect-ratio, the discrepancy is glaring, the theoretical thrust being far in defect of the real ones. The reason is not far to seek. The theory might give an approximate idea of the state of affairs in front of the plane, but the dead water which it assumes for the region behind is far from what experiments justify us to do. On the contrary, the region behind the plane is put into a state of violent disturbance and the motion inside is often opposite to that outside. The phenomenon of suction thus brought in accounts for the diminution of pressure behind the plane and consequently increase of pressure in front. The actual steps by which the final stage is reached are beautifully illustrated by a series of photographs taken by Prof. Prandtl and his assistants in the "Versuchsanstalt at Göttingen" and the exposition of the exact process by which the stable state is attained is given by Prof. Prandtl as follows :

"Betrachtet man z.B. den Beginn der Bewegung eines unendlich langen Flügels aus der Ruhe heraus, so ist sicher die Zirkulation zu Anfang gleich null; da aber nach einem bekannten Satz in einer reibungslosen Flüssigkeit bei Abwesenheit zirkulatorischer Kräfte die Zirkulation auf jeder geschlossenen "flüssigen Linie" zeitlich unveränderlich ist, muss beim Entstehen der Zirkulation um den Flügel ein Wirbel von gleicher aber entgegengesetzter Zirculation in der Flüssigkeit auftreten, damit der Satz für eine flüssige Linie gelten kann, die so gelegt ist, dass sie das vom Flügel bestrichene Flüssigkeitsgebiet umschlingt ohne es durchzusetzen. Beim endlichen Flügel müssen auch schon bei der stationären Bewegung Wirbel in der Flüssigkeit vorhanden sein,

denn nach dem Stokesschen Satze kann sich die Zirkulation auf einer geschlossenen Linie bei der Verschiebung nur dadurch ändern, dass Wirbellinien geschnitten werden. Bedenkt man aber, dass überall wo Auftrieb ist, auch Zirkulation sein muss, so findet man, dass eine den Flügel umschlingende Linie, wenn sie über ein Flügelende herübergestreift wird, notwendig Wirbel schneiden muss; denn wenn sie den Flügel verlassen hat, so muss auch ihre Zirkulation verschwunden sein. Dass in einer reibungslosen Flüssigkeit Wirbel gebildet werden, scheint zunächst im Widerspruch mit den Sätzen von Lagrange und Helmholtz zu stehn. Man muss jedoch bei allen Anwendungen der Hydrodynamik, die sich auf Wechselwirkungen zwischen der Flüssigkeit und festen Körpern beziehen, die Reibungslosigkeit durch einen Grenzübergang von einer sehr kleinen Reibung aus entstanden denken. In der Flüssigkeit mit kleiner Reibung ergibt sich eine Grenzschicht, in der Uebergang von der Körpergeschwindigkeit zur Geschwindigkeit der freien Strömung stattfindet. Diese Schicht, in der die Rotation von Null verschieden ist, verlässt den Körper, wenn die Bewegung hinreichend lang andauert und tritt damit als freie Wirbelschicht in das Innere der Flüssigkeit ein."

It is in this layer or "Grenzschicht" that viscosity comes into play, whereas in the outside fluid we can apply classical Hydrodynamics with success. This "Schicht" is the seat of innumerable vortices that are the cause of all outside disturbance due to a plane.

THEORY.

On the basis of these experiments and observations various theories of aeroplane motion have been built up; of these those offered by Prandtl, von Kármán and Betz have been found to yield most satisfactory results. In the following I have drawn largely upon Prandtl's conception that had to be a modified and remodelled to suit mathematical treatment.

To give this idea of "Grenzschicht" a mathematical basis, what is necessary is to divide the aeroplane surface into so many "differential surfaces" that each small elemental surface may be looked upon as an aeroplane on which fluid pressure is calculated independently of all other elements, and then it is integrated throughout the whole volume occupied by those elemental aeroplanes. The

conception is something like this: at each elemental aeroplane there is a circulation which is denoted by γ, and from the edges of this element vortices flow off with the fluid; the strength of the elemental vortices is ϵ. We can then picture the thing as follows: under each differential aeroplane there is a vortex of strength γ which is fixed with the element and from each element a vortex-line is flowing off with the liquid whose strength per unit volume is ϵ, so that the aeroplane becomes the seat of innumerable fixed vortices of strength γ per unit volume, and from the aeroplane free vortices are flowing off with the liquid like ribbons with strength ξ per unit volume.

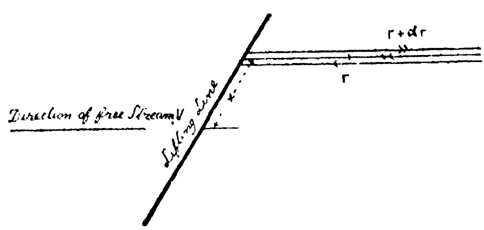
The vortices that go along with the fluid have been called "free vortices," and there remains another kind of vortices with the aerofoil which is denoted by "fixed vortices." Thus "fixed vortices" with the plane and "free vortices" flowing with the fluid form a conception of aeroplane motion starting from which we shall see how the presence of a plane influences its surroundings. In fact, for all practical purposes we can take away our aeroplane and look upon the fluid as scattered over by vortices according to a certain law which is determined by the geometrical dimensions and perspective of the plane.

The innumerable "bound vortices" which may for all purposes replace the plane will be supposed to be represented by a single line vortex which runs through the Centre of Pressure of the plane and ends at its extremities. This single line vortex will be called in the following the "lifting-line" Recently Dr. Birnbaum has suggested a modification of this theory of single line-vortex in the Zeitschrift für angewandte Mathematik und Mechanik, 1924. In this he has assumed that the distribution of the bound vortices along the breadth of the plane is not uniform, but varies according to certain laws. In other words, he has taken the single line vortex to run through the centre of gravity of the bound vortices rather than through the C. P. of the plane. He has, however, not calculated the corrections introduced by the modifications. This, it will be seen (page 95) will explain the small difference that still remains between my calculated values and those found from experiment.

Since the lift on the plane is found to decrease from the middle to the ends and since the lift is proportional to the circulation or vorticity of the "lifting-line," we may suppose the strength of the vortex-line decreasing from Γ_0 at the middle to zero at the ends.

Then according to the theorem of Stokes that by displacement of a closed curve round the vortex the circulation Γ can only change, if a corresponding quantity of vortex-filaments are cut, we must assume that vortex-filaments proceed off from the lifting-line. For a portion of the line of length dx the vortex strength is therefore to be written $(d\Gamma/dx)dx$ and per unit length of the line $(d\Gamma/dx)$.

This straightforward deduction from the Stokes Theorem can be put somewhat in a different way. We suppose a vortex filament of strength Γ, with a right-handed screw rotation coming from infinity behind the plane, meets the lifting-line at a distance x from the middle of the aeroplane to the right of the pilot. This filament then turns towards the right, forming a part of the lifting-line, goes a short distance dx along it, and then turns again to the right to leave the lifting-line and to go to infinity parallel to its incoming limb. Then another filament of strength $\Gamma + d\Gamma$ travelling from infinity in the same plane as the former one (here taken horizontal) meets the lifting-line at $x + dx$ and behaves as its predecessor did. Thus we see that at every point of the lifting-line a filament of strength Γ goes out and one of strength $\Gamma + d\Gamma$ comes in, leaving at every point of the line a vortex of strength $d\Gamma$ coming in, and adding to the strength of the single line-vortex which will have strength $\int d\Gamma = \Gamma$. The vortex filaments flowing off, closely side by side, form, taken as a whole, a surface like the figure which is known as "Vortex Sheet."



The strength of our vortex sheet remains unchanged during the whole flight, yet the separate parts of the sheet influence each other, and there takes place a gradual rolling up of the sheet. An exact theoretical investigation of this phenomenon has not yet been made; it can be said that the two halves of the sheet become concentrated more and more and finally at a great distance from the wing there remains a pair of vortices with a rather weak core. As a

first approximation I have not considered the latter development of this sheet of discontinuity which has been assumed, neglecting its small inclination, to run off from the lifting-line parallel to the free direction of the stream.

Various expressions for the law according to which the lift or the circulation varies with x, *i.e.*, with the distance from the middle of the plane, have been suggested. It is evident that it depends on the aspect-ratio and the perspective of the plane. A remarkable distribution of circulation was found in the form

$$\Gamma = \Gamma_0 \sqrt{1 - \frac{x^2}{l^2}}$$

where Γ_0 is the circulation at the middle and 'l' the half-span of the wing. This distribution is known as the Elliptic Distribution. One of its peculiar properties was found by Dr. M. Munk in the fact that it gave to a monoplane the smallest drag possible for it with the lift, the span and the velocity given. Dr. Betz afterwards suggested a distribution

$$\Gamma = \sqrt{1-\xi^2}\,(\Gamma_0 + \Gamma_2\xi^2 + \Gamma_4\xi^4 + \ldots)$$

where $\xi = (x/l)$. This was only a generalisation of the previous equation. But very little work has been done on aeroplane motion, either on the basis of the general or particular formula. All the previous workers have confined themselves to the comparatively simple case of Γ uniform over the whole span of the wing and dropping to zero at the ends where two vortices are assumed to trail off. This fact, apart from any other flaw in the theory, has vitiated the previous results to the extent of 30% to 50%. Another fact that commends Elliptic Distribution to our notice is that all observed distributions of lift deviate in most cases but slightly from it, so that results calculated with this can be expected to give a very good approximation to actual facts.

In the following, consequently, I have always considered Elliptic Distribution.

Lift and Drag.

On the above assumptions the force on each differential surface can be written down as $\rho(\gamma \times \mathfrak{w})$ per unit volume, where ρ is the density of the fluid, γ is the vortex-strength at that element and $\mathfrak{w}$ is the velocity of the fluid at that element, so that the force with which the aeroplane must be held to keep it fixed is given by

$$k = \rho \iiint (\gamma \times \mathfrak{w})\, dxdydz,$$

where the integration is throughout the whole volume filled by the vortices.

Now let us suppose that the bound vortices give rise to a velocity V_1 in the fluid and the free vortices ϵ to V_2, so that

$$\mathfrak{w} = V + V_1 + V_2 = V + V^*,$$

so that V^* is the velocity superimposed on the pure fluid due to the presence of the aeroplane with its vortices. Since $\gamma + \epsilon$ gives rise to the velocity V^*, then

$$\gamma + \epsilon = \text{curl } V^* = \nabla \times V^* ;$$

also we know that V is constant, so that

$$\nabla \times V = 0 ;$$

and since the free vortices are flowing off with the liquid so that the axis of ϵ is always parallel to $\mathfrak{w}$,

$$\epsilon \times \mathfrak{w} = 0 \quad \text{or} \quad (\nabla \times V_2) \times \mathfrak{w} = 0,$$

so that

$$k = \rho \iiint (\gamma \times \mathfrak{w})\, dxdydz$$

$$= \rho \iiint (\nabla \times V_1) \times (V + V^*)\, dxdydz$$

$$= \rho \iiint (\nabla \times V^*) \times (V + V^*)\, dxdydz,$$

$$\text{since } (\nabla \times V_2) \times \mathfrak{w} = 0$$

$$= \rho \iiint (\nabla \times V^*) \times V\, dxdydz + \rho \iiint (\nabla \times V^*) \times V^*\, dxdydz.$$

Now the first integral can be written

$$\rho \left[\iiint (\nabla \times V^*)\, dxdydz\right] \times V = \rho[\Gamma + E] \times V$$

where Γ and E are single equivalent vortices that can replace the bound and the free vortices respectively for all purposes.

For the second integral

$$I = \iiint (\nabla \times V^*) \times V^*\, dxdydz$$

we have from the following properties of vector analysis

$$(\nabla \times \mathrm{V}^*) \times \mathrm{V}^* = -\mathrm{V}^* \times (\nabla \times \mathrm{V}^*)$$

$$= -(\mathrm{V}^*.\mathrm{V}^*)\nabla + (\mathrm{V}^*.\nabla)\mathrm{V}^*$$

$$= (\mathrm{V}^*.\nabla)\mathrm{V}^* - \tfrac{1}{2}\nabla(\mathrm{V}^*.\mathrm{V}^*).$$

If u^*, v^*, w^* be the components of V^* along the three co-ordinate axes and i, j, k be three unit vectors along these lines, then

$$(\Delta \times \mathrm{V}^*) \times \mathrm{V}^* = \left(u^* \frac{\partial u^*}{\partial x} + v^* \frac{\partial u^*}{\partial y} + w^* \frac{\partial u^*}{\partial z} \right) i$$

$$+ \left(u^* \frac{\partial v^*}{\partial x} + v^* \frac{\partial v^*}{\partial y} + w^* \frac{\partial v^*}{\partial z} \right) j$$

$$+ \left(u^* \frac{\partial w^*}{\partial x} + v^* \frac{\partial w^*}{\partial y} + w^* \frac{\partial w^*}{\partial z} \right) k - \tfrac{1}{2}\nabla(q^{*2}),$$

where q^* is the scalar value of V^*.

Hence

$$\mathrm{I} = i\iiint \left(u^* \frac{\partial u^*}{\partial x} + v^* \frac{\partial u^*}{\partial y} + w^* \frac{\partial u^*}{\partial z} \right) dx\,dy\,dz$$

$$+ j\iiint \left(u^* \frac{\partial v^*}{\partial x} + v^* \frac{\partial v^*}{\partial y} + w^* \frac{\partial v^*}{\partial z} \right) dx\,dy\,dz$$

$$+ k\iiint \left(u^* \frac{\partial w^*}{\partial x} + v^* \frac{\partial w^*}{\partial y} + w^* \frac{\partial w^*}{\partial z} \right) dx\,dy\,dz$$

$$- \tfrac{1}{2}\iiint \nabla(q^{*2})\,dx\,dy\,dz.$$

Now

$$\iiint \left(u^* \frac{\partial u^*}{\partial x} + v^* \frac{\partial u^*}{\partial y} + w^* \frac{\partial u^*}{\partial z} \right) dx\,dy\,dz$$

$$= \iiint u^* \frac{\partial u^*}{\partial x}\,dx\,dy\,dz + \iiint v^* \frac{\partial u^*}{\partial y}\,dx\,dy\,dz$$

$$+ \iiint w^* \frac{\partial u^*}{\partial z}\,dx\,dy\,dz.$$

Integrating by parts, this is

$$=\iint\left\{u^*u^*-\int u^*\frac{\partial u^*}{\partial x}dx\right\}dydz+\iint\left\{u^*v^*-\int u^*\frac{\partial v^*}{\partial y}\right\}dzdx$$

$$+\iint\left\{u^*w^*-\int u^*\frac{\partial w^*}{\partial z}dz\right\}dxdy.$$

Now if we consider an element of surface ds at (x, y, z) and if l, m, n be the direction cosines of its normal

$$dydz=lds,\quad dzdx=mds,,\quad dxdy=nds,$$

so that

$$\iiint\left(u^*\frac{\partial u^*}{\partial x}+v^2\frac{\partial u^*}{\partial y}+w^*\frac{\partial u^*}{\partial z}\right)dxdydz$$

$$=\iint lu^*+mv^*+nw^*)u^*ds-\iiint\left(\frac{\partial u^*}{\partial x}+\frac{\partial v^*}{\partial y}+\frac{\partial w^*}{\partial z}\right)u^*dxdydz.$$

As the liquid is homogeneous and incompressible

$$\frac{\partial u^*}{\partial x}+\frac{\partial v^*}{\partial y}+\frac{\partial w^*}{\partial z}=0.$$

Hence

$$I=\iint(lu^*+mv^*+nw^*)(iu^*+jv^*+kw^*)ds-\tfrac{1}{2}\iiint\nabla(q^{*2}),$$

where the surface integral is over a surface enclosing all the vortices and the volume integral throughout a space covered by the vortices.

Now $$\nabla(q^{*2})=2q^*\nabla(q^*)$$

$$\therefore\quad\iiint\nabla(q^{*2})dxdydz=2\iiint q^*\nabla(q^*)dxdydz$$

$$=2i\iiint q^*\frac{\partial q^*}{\partial x}dxdydz+2j\iiint q^*\frac{\partial q^*}{\partial y}dxdydz$$

$$+2k\iiint q^*\frac{\partial q^*}{\partial z}dzdxdy$$

$$=i\iint lq^{*2}ds+j\iint mq^{*2}ds+k\iint nq^{*2}ds$$

$$=\iint(li+mj+nk)q^{*2}ds=\iint Nq^{*2}ds,$$

where N is the unit normal vector to the element of the surface ds.

Therefore

$$I = \iint (lu^* + mv^* + nw^*) V^* ds - \tfrac{1}{2} \iint N q^{*2} ds ;$$

then

$$k = \rho (\Gamma + E) \times V + \rho \iint (lu^* + mv^* + nw^*) V^* ds - \tfrac{1}{2} \rho \iint N q^{*2} ds.$$

Now Γ is 'Γl' of the Kutta-Jonkowski formula for lift, so that $(\rho (\Gamma \times V)$ is a force perpendicular to V, and according to Prof. Gibbs's conception, if V be horizontal, from left to right, and Γ along the length of the aeroplane from behind forward, then the force is vertically downward, hence it is opposite to " lift " and equivalent in amount to it. The force $\rho (E \times V)$ is also perpendicular to V, hence its component along V is zero and, it being of a higher order of small quantities, $\rho (\Gamma \times V)$, its effect on the latter force, *i.e.*, the lift, is negligible. Hence to a first order of approximation

$$E \times V = 0.$$

Now the integral $\rho \iiint (\gamma \times \mu r) dx dy dz$ is to be integrated throughout the whole space covered by the vortices. But if we extend the limits of integration so as to make them infinite, we do not thereby change the value of the integral, because outside the space where the vortices are the value of the integrand is zero, as at every point there $\gamma = 0$. So we can take all the integrals over infinite space. For the surface integrals let us assume that we enclose the volume by a cylindrical surface and two parallel planes so that the axis of the cylinder is parallel to V and passes through the aeroplane and the two planes, one A_1 is in front of the aeroplane and the other A_2 is behind the aeroplane and they are perpendicular to the axis of the cylinder If now we take the radius R of the cylinder very great, both the surface integrals would vanish over it, since the velocities are of order $(1/R^2)$ and ds of order R^2. Also the value of these two surface integrals over A_1 will vanish if we take A_1 sufficiently far off from the aeroplane. As to the values of these integrals over A_2 we must remark that the velocities

$$q^* \quad V^* \quad u^* \quad v^* \quad w^*$$

are composed of two parts; one is due to the bound vortices and the other one to the free vortices, so that

$$q^* = q_1 + q_2, \quad V^* = V_1 + V_2, \quad u^* = u_1 + u_2,$$

$$v^* = v_1 + v_2, \quad w^* = w_1 + w_2.$$

Now we see that as we move the plane A_2 further and further away from the aeroplane always parallel to itself, the quantities

$$q^* \quad V^* \quad u^* \quad v^* \quad w^*$$

approximate more and more to

$$q_2 \quad V_2 \quad u_2 \quad v_2 \quad w_2$$

and the influence of the bound vortices becomes feebler and feebler so that ultimately, when the plane A_2 is far off enough from the aeroplane, we can take with sufficient degree of approximation

$$q^*=q_2, \quad V^*=V_2, \quad u^*=u_2, \quad v^*=v_2, \quad w^*=w_2$$

and the surface integrals become

$$\rho.\iint(lu_2+mv_2+nw_2)V_2 ds-\tfrac{1}{2}\rho N\iint q_2^2 ds.$$

Now

$$lu_2+mv_2+nw_2$$

is the component of the velocity due to the free vortices normal to A; but we have so taken the plane A_2 that it is perpendicular to V, *i.e.*, perpendicular to the direction of the vortices which are parallel to each other and to V when far off from the aeroplane, so that the normal components of the velocities generated by the free vortices are zero, *i.e.*, the first of the above two integrals are zero. Hence we get

$$k=\rho(\Gamma \times V)-\tfrac{1}{2}\rho N\iint q_2^2 ds.$$

Thus we see that, to keep the aeroplane in position, this force k must be applied on the aeroplane, which easily resolves itself into two parts perpendicular to each other. Thus the air force on the aeroplane can be resolved into two parts; one is what is called Lift and is equal to

$$\rho(\Gamma \times V)$$

and is perpendicular to V and upwards; whereas the other portion is what is called Drag and is equal to

$$\tfrac{1}{2}\rho\iint q_2^2 ds$$

and is parallel and in the same direction as V. From this expression of drag it is at once apparent that the drag is exactly equivalent to

that portion of the energy which is flowing off with the fluid in the free vortices and will ultimately be dissipated into the air as heat.

The expression for Lift

$$\rho' \Gamma \times V$$

was known before, having been found by Kutta and Jonkowsky independently of each other.

My expression

$$\tfrac{1}{2}\rho N \iint q_2^2 ds$$

gives for the first time an explanation for the phenomena of Drag of a viscous fluid. It has always been vaguely thought that Drag must be due to the part of the energy which is being carried off by the fluid. But the above treatment proves it conclusively.

In the above and in the following pages the whole effect of the aeroplane motion has been divided into two parts—one due to the viscosity of the medium and the other due to the presence of the plane in the medium. We have seen that the effect of viscosity is confined to the 'Grenzschicht,' which is small in comparison with the other effect—my remaining work being confined to this. Prof. von Kármán has been doing a great deal of work on the viscous effect.

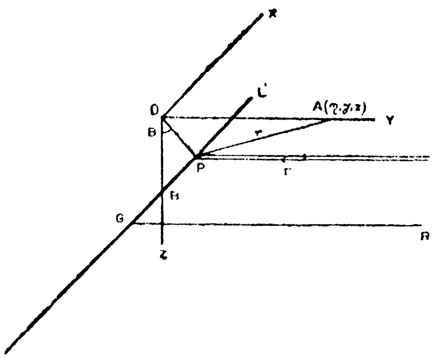
Induced Velocity.

We know that fluids have a sort of viscosity which generally makes itself felt in the immediate neighbourhood of a surface over which the fluid passes. Thus when the flowing fluid strikes an obstacle, the layer of fluid in contact with the body is brought to rest, the next layer has a small slipping velocity, the next layer a little higher velocity which from layer to layer increases to the velocity of the free fluid. It is this series of layers, whose thickness is very small, that is called "Grenzschicht"; and it is in this layer that viscosity comes into play, whereas in the outside fluid we can apply classical Hydrodynamics with success. Prof. Fuchs remarks in this connection that "Wir werden aber sehen dass diese beiden Gebiete fortwährend aufeinander *einwirken, indem die freie Flüssigkeit die Druck*-verhältnisse in der Grenzschicht regelt und die Grenzschicht ihrerseits fortwährend die Strömung, hauptsächlich hinter dem Körper,

dadurch umgestaltet, dass von ihnen aus Wirbel in den freien Flüssigkeitsraum hinausgehen."

Thus we see that, neglecting smaller quantities of higher order, the viscous effect, *i.e.*, the effect due to viscosity, and the induced effect, *i.e.*, the effect due to the plane, might be superimposed linearly and the combined effect calculated. In what follows I have considered induced effect only.

We have already seen that we can replace the plane by a single line-vortex called lifting-line and a series of free vortices trailing off from it. Let A be the point in the fluid at which induced effects are to be found. Let O be the foot of the perpendicular from A on the vertical plane through the lifting-line LGL'. OX is drawn parallel to LL', *i.e.*, the plane OX, OY is horizontal and parallel to the vortex sheet LGL', R. Let the co-ordinates of A with reference to G be (x, y, z) and the distance



$$BP=c, \quad PA=r, \quad OP=a, \quad <OPA=\alpha, \quad <BOP=\beta.$$

At P we have assumed a vortex Γ coming in and going out at the extremities dx of an element of the lifting-line. The incoming vortex at P generates at A a velocity which, when resolved along the three axes, is

$$u=\frac{\Gamma x}{4\pi a^2}\left(1+\frac{y}{r}\right)$$

$$v=0$$

$$w=-\frac{\Gamma z}{4\pi a^2}\left(1+\frac{y}{r}\right).$$

The pair of vortices at P having the same strength, but different rotations produces then a velocity which can be written as the

difference of the effects of the two vortices at P which are close together.

$$\therefore \quad du_1 = -\frac{\partial u}{\partial x}\,dx, \qquad dv_1 = 0, \qquad dw_1 = -\frac{\partial w}{\partial x}\,dx$$

To these we shall have to add the velocity imposed by the vortex element dx at P

$$du_2 = 0, \quad dv_2 = -\frac{\Gamma dx}{4\pi}\cdot\frac{z}{r^3}, \quad dw_2 = \frac{\Gamma dx}{4\pi}\cdot\frac{y}{r^3}.$$

Hence the velocity at A due to the complete vortex at P is

$$du = \frac{\Gamma dx}{4\pi}\left[(1+\sin\alpha)\frac{\sin 2\beta}{a^2} + \frac{\sin\alpha\sin 2\beta}{2r^2}\right]$$

$$dv = -\frac{\Gamma dx}{4\pi}\cdot\frac{\cos\alpha\cos\beta}{r^2}$$

$$dw = \frac{\Gamma dx}{4\pi}\left[(1+\sin\alpha)\frac{\cos 2\beta}{a^2} + \frac{\sin\alpha\cos^2\beta}{r^2}\right].$$

The elemental velocity 'du' shows that the fluid, which before the introduction of the plane was flowing in the direction of the y-axis, has now a velocity in the direction of the length of the plane; that this is the case is proved experimentally and will also be clear, if we consider the flow in the immediate neighbourhood of the surface of the wing. Since the excess of pressure below the wing and the defect above it must vanish as one goes beyond the side edges of the wing, there must be a fall in pressure near these edges, which is directed outward on the lower side of the wing and inward on the upper. The oncoming flow under the influence of this pressure-drop, whilst it passes over the wing, will receive on the lower side an additional component side-ways and outward, on the upper side inward, which does not vanish later.

The component 'dv' is very small in comparison with the velocity V of the free stream and generally its effects are neglected.

The elemental velocity 'dw', which when integrated over the entire length of the wing gives the complete downward velocity of the fluid at A due to the presence of the wing, plays an important part

in determining the behaviour of a monoplane and biplane. This downward velocity is technically known as "Downwash."

Aerodynamically "Downwash" is much more important than du and dv; and I have considered 'dw' only in the following pages, du and dv offering less difficulty and interest.

Substituting in the expression for 'dw'

$$\Gamma = \Gamma_0 \sqrt{1-\xi^2}, \qquad \text{where} \qquad \xi = \frac{x+\eta}{l}$$

and integrating over the whole span of the wing, we get

$$w = \frac{\Gamma_0 l}{4\pi} \int_{-1}^{1} \left[\left(1 + \frac{y}{r}\right) \frac{z^2 - x^2}{(z^2+x^2)^2} + \frac{y}{r^3} \cdot \frac{z^2}{a^2} \right] \sqrt{1-\xi^2}\, d\xi,$$

$$= \frac{\Gamma_0 l}{4\pi} (w_1 + w_2 + w_3 + w_4 + w_5)$$

where

$$w_1 = \int_{-1}^{1} \frac{z^2(1-\xi^2)}{[z^2 + (l\xi-\eta)^2]^2} \cdot \frac{d\xi}{\sqrt{1-\xi^2}}$$

$$w_2 = -\int_{-1}^{1} \frac{(l\xi-\eta)^2(1-\xi^2)}{[z^2 + (l\xi-\eta)^2]^2} \cdot \frac{d\xi}{\sqrt{1-\xi^2}}$$

$$w_3 = \int_{-1}^{1} \frac{yz^2(1-\xi^2)}{[z^2 + (l\xi-\eta)^2]^2} \cdot \frac{d\xi}{\sqrt{(1-\xi^2)[z^2+y^2+(l\xi-\eta)^2]}}$$

$$w_4 = -\int_{-1}^{1} \frac{y(l\xi-\eta)^2(1-\xi^2)}{[z^2 + (l\xi-\eta)^2]^2} \cdot \frac{d\xi}{\sqrt{(1-\xi^2)[z^2+y^2+(l\xi-\eta)^2]^3}}$$

$$w_5 = \int_{-1}^{1} \frac{yz^2(1-\xi^2)}{[z^2 + (l\xi-\eta)^2]^2} \cdot \frac{d\xi}{\sqrt{(1-\xi^2)[z^2+y^2+(l\xi-\eta)^2]^3}}.$$

If now we make a few substitutions and an assumption which is quite justified in aerodynamical calculations

$$\frac{z}{l} = \lambda, \qquad \frac{y}{l} = \mu, \qquad \frac{\eta}{l} = \nu$$

$$\nabla = \lambda^2 + (1-\nu)^2, \qquad \Delta = \sqrt{(1-\xi^2)[\lambda^2 + (\xi-\nu)^2]}$$

and

$$\mu^2 < [\lambda^2 + (\xi-\nu)^2],$$

we get

$$w_1 = \frac{\lambda^2}{l^2}\int_{-1}^{1} \cdot \frac{1-\xi^2}{\nabla^2} \cdot \frac{d\xi}{\sqrt{1-\xi^2}}$$

$$w_2 = -\frac{1}{l^2}\int_{-1}^{1} \frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^2} \cdot \frac{d\xi}{\sqrt{1-\xi^2}}$$

$$w_3 = \frac{\lambda^2\mu}{l^2}\int_{-1}^{1} \frac{1-\xi^2}{\nabla^2} \cdot \frac{d\xi}{\Delta}\left(1-\frac{1}{2}\frac{\mu^2}{\nabla}+\frac{3}{8}\frac{\mu^4}{\nabla^2}+\ldots(-1)^n\frac{\underline{|2n}}{(2\underline{|n})^2}\frac{\mu^{2n}}{\nabla^n}\right)$$

$$w_4 = -\frac{\mu}{l^2}\int_{-1}^{1} \frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^2} \cdot \frac{d\xi}{\nabla}\left(1-\frac{1}{2}\frac{\mu^2}{\nabla}+\frac{3}{8}\frac{\mu^4}{\nabla^2}+\right.$$

$$\left.\ldots\ldots + (-1)^n\frac{\underline{|2n}}{(2\underline{|n})^2}\frac{\mu^{2n}}{\nabla^n}\right)$$

$$w_5 = \frac{\lambda^2\mu}{l^2}\int_{-1}^{1} \frac{1-\xi^2}{\nabla^2}\frac{d\xi}{\Delta}\left(\mu-\frac{3}{2}\frac{\mu^3}{\nabla}+\frac{15}{8}\frac{\mu^5}{\nabla^2}\frac{d\xi}{\Delta}+\right.$$

$$\left.\ldots+(-1)^n\frac{3\cdot5\ldots2n+1}{2\cdot4\ldots2n}\frac{\mu^{2n+1}}{\nabla^n}\right).$$

Substituting these values in the expression for 'w' and arranging in ascending order of μ, we get the induced velocity at A

$$w = \frac{\Gamma_0 l}{4\pi}\left[\frac{\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{\nabla^2}\frac{d\xi}{\sqrt{1-\xi^2}} - \frac{1}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}\right]$$

$$+\frac{\Gamma_0 l}{4\pi}\left[\frac{2\lambda^2\mu}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{\nabla^2}\cdot\frac{d\xi}{\Delta}-\frac{\mu}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^2}\cdot\frac{d\xi}{\Delta}\right]$$

$$-\frac{\Gamma_0 l}{4\pi}\left[\frac{2\lambda^2\mu^3}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{\nabla^3}\cdot\frac{d\xi}{\Delta}-\frac{1}{2}\frac{\mu^3}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^3}\cdot\frac{d\xi}{\Delta}\right]$$

$$+ \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots$$

$$+\frac{\Gamma_0 l}{4\pi}\left[(-1)^n\frac{2(n+1)\lambda^2\mu^{2n+1}}{l^2}\cdot\frac{1\cdot3\cdot5\ldots\ldots(2n-1)}{2\cdot4\ldots\ldots2n}\int_{-1}^{1}\frac{1-\xi^2}{\nabla^{n+2}}\cdot\frac{d\xi}{\Delta}\right.$$

$$\left.+(-1)^{n-1}\frac{\mu^{2n+1}}{l^2}\cdot\frac{1\cdot3\cdot5\ldots\ldots(2n-1)}{2\cdot4\ldots\ldots2n}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^{n+2}}\cdot\frac{d\xi}{\Delta}\right]$$

In aeroplanes without any stagger the part of the induced velocity which is most important is given by the first term of the above series. It is the induced velocity in the vertical plane through the lifting-line. We shall denote it by 'w_0'. Hence putting $\mu=0$ or $y=0$ in 'w' we get

$$w_0=\frac{\Gamma_0 l}{4\pi}\left[\frac{\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}\right.$$

$$\left.-\frac{2}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{\nabla^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}\right].$$

Our present problem now reduces itself to finding the values of the above two integrals. The whole process of integration will not be shown, but a few steps will be indicated in the following.

If we substitute in the first integral of the above expression for 'w_0'

$$\xi=\frac{q+y}{1+qy},$$

with a relation for q in the form

$$q+\frac{1}{q}=\frac{\lambda^2+\nu^2+1}{\nu}$$

we obtain

$$\frac{\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}=\frac{\lambda^2(1-q^2)^{\frac{3}{2}}}{l^2}\int_{-1}^{1}\frac{(1-y^2)(1+qy)}{(A+By^2)^2}\cdot\frac{dy}{\sqrt{1-y^2}}$$

where

$$A=\lambda^2+(\nu-q)^2$$

and

$$B=\lambda^2q^2+(1-\nu q)^2.$$

The relation for 'q' shows that there are two values of 'q', one greater than 'l' and another less than 'l', both being of the same sign, positive, and one being reciprocal of the other. We shall take that value of q which is less than 'l', as the other will make the integral imaginary. It can easily be seen that one part of the above integral is zero, while by substituting

$$m=\frac{B}{A}=\frac{1-q\nu}{\nu-q}\,q==\left(\frac{1-q\nu}{\lambda}\right)^2$$

the other part can be written in the form

$$\frac{\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}=\frac{\lambda^2(1-q^2)^{\frac{3}{2}}}{l^2A^2}\int_{-1}^{1}\frac{1-y^2}{(1+my^2)}\cdot\frac{dy}{\sqrt{1-y^2}}$$

Writing again

$$y^2=\frac{x^2}{1+m-mx^2}$$

the integral reduces to

$$\frac{\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}=\frac{2x^2(1-q^2)^{\frac{3}{2}}}{A^2l^2(1+m)^{\frac{1}{2}}}\int_0^1(1-x^2)\frac{dx}{\sqrt{1-x^2}}$$

$$=\frac{\lambda^2(1-q^2)^{\frac{3}{2}}}{A^2l^2(1+m)^{\frac{1}{2}}}\cdot\frac{\pi}{2}.$$

For the other integral with the same substitutions we get

$$-\frac{1}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi^2)}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{1-\xi^2}}=-\frac{(1-q^2)^{\frac{3}{2}}(\nu-q)^2}{l^2A^2(1+m)^{\frac{1}{2}}}\cdot\frac{\pi}{2}$$

$$-\frac{(1-q^2)^{\frac{3}{2}}}{l^2A^2(1+m)^{\frac{1}{2}}(m+q)^2}\cdot\frac{\pi}{2}$$

$$-\frac{(1-q^2)^{\frac{9}{2}}}{l^2A^2(1+m)^{\frac{1}{2}}(m+q^2)^2}\cdot\pi+\frac{(1-q^2)^{\frac{9}{2}}}{l^2A^2(m+q^2)^2}\cdot\pi.$$

Hence the whole expression for 'w_0' with the substitution $m=\tan^2 a$ becomes

$$w_0=\frac{\Gamma_0}{4l}\left[1-\frac{\cos a}{\sqrt{1-q^2}}\right]$$

If in this expression we put

$$\Gamma_0 = \frac{4A}{\pi\rho V.2l}$$

for Elliptic Distribution, where A is the lift and

$$A = C_a . F . q = C_2 . 4lt . \tfrac{1}{2}\rho v^2 ,$$

where $2t$ is the breadth of the plane,

then $$w_0 = \frac{C_a}{s} . \frac{V}{\pi} \left[1 - \frac{\cos a}{\sqrt{1-q^2}}\right],$$

where C_a is the lift-coefficient, s the aspect-ratio and V the velocity of the wing; and the quantities remain constant for a wing so long as its angle of attack remains constant. Hence

$$kw_0 = 1 - \frac{\cos a}{\sqrt{1-q^2}} .$$

In the expression for kw_0, two quantities λ and ν are independent variables. For particular values of λ, we might construct $(kw_0 - \nu)$ curves. These curves have been plotted and published in the Zeitschrift für angewandte Mathematik and Mechanik, 1924. They tally remarkably well with those plotted by Prof. Prandtl experimentally and published in his paper " Der induzierte Widerstand des Mehrdeckers.

The peculiar property of a constant induced velocity over the whole span of the wing deduced by Dr. M. Munk can be easily seen from the fact that on the wing $\lambda=0$, and because

$$\cos a = \frac{\lambda}{\sqrt{\lambda^2 + (1-q\nu)^2}} = 0, \qquad kw_0 = 1 \quad \text{or} \quad w_0 = \frac{C_a}{s} . \frac{V}{\pi},$$

which is constant over the whole span of the wing.

It is apparent that the downwash kw_0, which is measured positive downwards, can become negative for certain values of λ and ν; and this reversal of the intrinsic characteristic of downwash is expected to occur towards the ends of the wing. This theoretical deduction of mine has been verified experimentally in the " Aerodynamische Versuchsanstalt zu Göttingen."

The Induced "Angle of Attack".

We have seen before that, owing to the vortex-system of one wing of an aeroplane, the velocity-field near the wing is disturbed, and if in this disturbed field we bring in another wing, this wing will find itself in a flowing system of fluid whose stream-lines are no longer as they are in an undisturbed system, and consequently we can anticipate a change in the lift-capacity and the drag of this second wing. In fact, it has been amply verified by experiments in the Aerodynamische Versuchsanstalt in Göttingen that the lift-capacity of a biplane without any stagger and décalage is decided by less than the sum of the lift-capacity of the wings. In fact, a transformation formula was suggested in the "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen" Lieferung I; but when this formula was put to the test, it gave results which fell from thirty to fifty per cent. short of the experimental result. In this part of my paper I have suggested a new transformation formula which has been found to yield results in almost perfect agreement with the experimental ones. (See page 96.) The importance of this formula lies in the fact that it is the angle of attack of a wing with reference to which all its measurements are tabulated; another utility is the ease with which it allows the angle to be theoretically calculated, without going through a series of very exact experiments, from the experimentally determined angle of attack of a monoplane.

The basic principles of this transformation are as follows:—

It is assumed that a wing experiences the same lift as in an undisturbed air-stream, if it cuts the stream-lines of the flow disturbed by the other wing in the same manner as a monoplane wing cuts the straight stream-line of the undisturbed flow. As is easily seen, the wing-profil must be in general slightly turned and its curvature slightly altered. By the rotation of the wing the direction of the resultant air force acting on it is turned through an equal angle. Furthermore, since the curvature of the stream-lines near the second wing will be altered, the point of pressure will also be altered. We shall now examine these effects one by one and express them quantitatively.

As is generally known and as has been referred to before, the downwash of a wing modifies its own lift-capacity, *i.e.*, its angle of attack

through an amount given by $tan^{-1} \frac{w_0}{V}$, where 'w_0' is the downwash-velocity on the wing and V the velocity of the free stream at infinity. But when this wing comes into a region already disturbed by the presence of another wing, its lift-capacity for the same geometrical angle of attack suffers another modification. It has been found experimentally that C_a, the lift-coefficient, is a linear function of the angle of attack, and when the length of the wing is infinite, theory gives us for a circular wing of unit breadth

$$C_a = 2\pi\,(a_\infty + \beta)$$

where λ, the angle of attack, is small and λ is the "Wölbungswinkel," *i.e.*, the angle which the sectional arc of the wing subtends at its centre, so that

$$\sin \beta/2 = t/R_1,$$

where $2t$ is the sectional chord and R_1 the radius of the arc. Now this angle of attack a_∞, which is called the angle of attack for a wing of unlimited length, cannot be found directly from experiments, as when the plane is of unlimited length, the downwash, as we have seen before, is absent, so that the angle between the chord of the aeroplane section and the direction of flow of air current gives the angle of attack; but when we have to do with a finite length of the plane, this downwash comes in so that what is the real direction of the current at infinity (*i.e.*, at a very great distance from the plane) is no longer the real direction in which the air-current strikes the chord of the plane and the geometrical angle of attack is consequently not the real or effective angle of attack of the aeroplane. So in the case of a monoplane, when we have to calculate the lift from the geometrical angle of attack, we have to transform the geometrical angle of attack, which is measured from experiments, to the effective angle of attack at which the wind really strikes the chord. This formula of transformation is

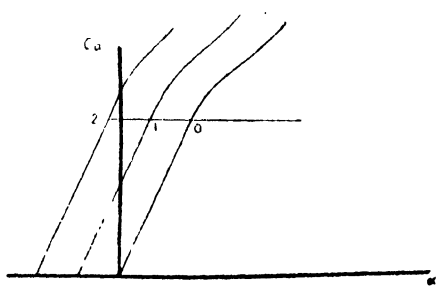
$$a_E = a_\infty + \tan^{-1} \frac{w}{V}.$$

As we have remarked at the beginning, as soon as a plane is set in a stream of fluid flowing steadily in one direction, the stream-lines of the flow modify themselves so as to embrace the plane completely and assume a curvature which varies from point to point. If now in the region of stream-lines of varying curvature we introduce another

plane, its geometrical angle of attack will differ furthermore from its effective angle of attack. In fact, the diminution of the angle of attack is due to two causes, which are connected with the curvature of stream-lines. Therefore if α be the geometrically measured angle of attack, *i.e.*, if α be the angle between the chord of the second wing and the direction of V, then due to its own downwash this angle will suffer a diminution of $\tan^{-1}\frac{w_0}{V}$, and now, as it acts as the second wing of a biplane, its angle is again altered by the induced downwash of the other wing, the effect of the curvature of the stream-lines and the effect brought about by the consequent shifting of the centre of pressure.

First Effect: Effect of the curvature of the stream lines on the angle.

Suppose we have three planes 0, 1, 2, of which 0 has no curvature, 1 has a curvature $1/R_1$ and 2 a curvature of $1/R_2$. It has been found from experiments that the relation between C_a, the lift-coefficient, and α the angle is given by the accompanying figure for 0, 1, 2. Thus it is apparent that 2 has a smaller angle of attack than 1 and 1 a smaller one than 0 for the same lift-coefficient C_a. This fact can be theoretically expressed by the relation



$$A = C_a . F . q = \tfrac{1}{2} C_a . F . \rho v^2 = 2\pi \rho / v^2 \frac{\sin(\alpha + \beta/4)}{\cos(\beta/4)} .$$

If 'f' denote the height of the middle point of the arc from that of the chord, then

$$\frac{f}{l} = \tan\frac{\beta}{4} \quad \text{and} \quad R_1 = \frac{f^2 + l^2}{2l} \quad \therefore \quad \frac{l}{R_1} = \frac{\beta}{2}$$

Hence

$$C_a = 2\pi \frac{\sin\left(\alpha + \frac{\beta}{4}\right)}{\cos\frac{\beta}{4}} = 2\pi\left(\alpha + \frac{\beta}{4}\right) = 2\pi\left(\alpha + \frac{l}{2R_1}\right).$$

From this it is apparent that if we want to have the same lift-coefficient C_a for the three planes, the angle must be diminished by amounts $\frac{t}{2R_1}$ for 1 and $\frac{t}{2R_2}$ for 2. Thus when the stream-lines are straight, the effect of the curvature of the plane is to diminish the angle for the same lift-coefficient by $\frac{t}{2R_1}$.

If now we want to find the effect of a curvature in the stream-lines on a plane which has also a curvature of its own, then if $1/R$ be the curvature of the stream-lines and $(1/R_1)$ that of the plane, the effective curvature of the plane is only $\frac{1}{R_1} - \frac{1}{R}$. By effective curvature is meant the curvature of the plane which is effective in bringing about a diminution of the angle of attack. Therefore in this case, when a curved plane finds itself in a stream whose stream-lines have a curvature of their own: to have the same lift-coefficient C_a, as it had when the stream was straight, the angle must be diminished by

$$\frac{t}{2}\left(\frac{1}{R_1} - \frac{1}{R}\right)$$

Thus the geometrical angle of attack of a plane which has a curvature of its own and finds itself in a curved stream must be diminished by

$$\frac{t}{2R_1} - \frac{t}{2}\left(\frac{1}{R_1} - \frac{1}{R}\right) = \frac{t}{2R}.$$

This is the correction in the angle due to the curvature of the stream-lines.

Second Effect: Effect of the shifting of the centre of pressure of the plane on its angle of attack.

The point where the whole force of the stream acts on the plane is called the centre of pressure, and if 's' be its distance from the middle of the plane measured along the chord of the section, then the diminution of the geometrical angle through this shifting is $\frac{s}{R}$. In aerodynamical experiments, by the geometrical angle of attack is understood that angle which the undisturbed stream-direction of V makes with the chord joining the extremities of the sectional arc of

the plane. In the case when $\alpha=0$, the front and rear edges A and B of the plane of infinite length lie in the same horizontal line. If, however, instead of a horizontal stream an inclined and curved stream of fluid flows in, we shall have to locate the edges on this stream-line. The chord AB is always parallel to the tangent to the stream-line at M, the middle point of the arc. The inclination of the tangent at D' (which is vertically over the C.P. of the lower wing) to the horizon is $\tan \frac{w}{V}$ and the inclination of the tangent at M exceeds this by $\frac{s}{R}$.

Thus we see that, if α_D be the geometrically measured angle of attack of the second wing of a biplane and if α_∞ denote its real or effective angle, *i.e.*, α_∞ is that angle which will give the same lift to a plane of the same dimensions but of infinite length, and if w_0 be the velocity of the fluid which the upper wing generates on itself by its own downwash and if w'_0 be the corresponding velocity generated by the lower wing on the upper and if V be the velocity of the stream at infinity, then

$$\alpha_D = \alpha_\infty + \tan^{-1}\frac{w_0}{V} + \tan^{-1}\frac{w_0'}{V} + \frac{t}{2R} + \frac{s}{R}.$$

If now w_0' be small in comparison with V, which in reality it always is, then

$$\tan^{-1}\frac{w_0}{V} = \frac{w_0}{V}$$

and s can easily be put in the form

$$t - s = \frac{C_m}{C_a} \cdot 2t,$$

where C_a and C_m are the lift- and moment-coefficients of the wing.

$$\therefore \quad \alpha_D = \alpha_\infty + \frac{w_0}{V} + \frac{w_0'}{V} + \frac{t}{2R} \left(1 - 2\frac{C_m}{C_a}\right)\frac{t}{R}$$

$$= \alpha_\infty + \frac{w_0}{V} + \frac{w_0'}{V} + \frac{2t}{R}\left(\frac{3}{4} - \frac{C_m}{C_a}\right)$$

$$= \alpha_E + \frac{w_0'}{V} + \frac{2t}{R}\left(\frac{3}{4} - \frac{C_m}{C_a}\right).$$

In the former section we have found an expression for the induced velocity at any point of the fluid. There we have seen that w varies from point to point of the fluid, so that the inclination

$$\phi=\tan^{-1}\frac{w}{V}=\frac{w}{V}$$

of the stream-lines varies from point to point also. Therefore the curvature of the stream-lines in the plane perpendicular to the length of the wing is given by

$$\frac{1}{R}=\frac{\partial\phi}{\partial y}=\frac{1}{V}\frac{\partial w}{\partial y}.$$

We would do well here to remind ourselves that the stream-lines, strictly speaking, are not plane curves, because the component of the superimposed velocity of the stream in the direction of the length of the wing brings in at different places different contributions, so that stream-lines are no longer plane curves but space curves with double curvature. In what follows we shall neglect this second curvature. Again, we shall here restrict ourselves to finding the curvature of the stream-lines as they cross the vertical plane through the "lifting line," *i.e.*,

$$\frac{1}{R_0}=\frac{1}{V}\left(\frac{\partial w}{\partial y}\right)_{y=0}.$$

We have seen on page 74 that w can be expressed in a series of ascending powers of μ. Hence differentiating w with respect to y and putting $y=l\mu=0$ we get

$$\left(\frac{\partial w}{\partial y}\right)_0=\frac{\Gamma_0}{4\pi}\left[\frac{2\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{\nabla^2}\cdot\frac{d\xi}{\Delta}-\frac{1}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi)^2}{\nabla^2}\cdot\frac{d\xi}{\Delta}\right].$$

Now dropping the suffix of $\frac{1}{R_0}$ we get

$$\frac{1}{R}=\frac{1}{V}\left(\frac{\partial w}{\partial y}\right)_0$$

$$=\frac{\Gamma_0}{4\pi V}\left[\frac{2\lambda^2}{l^2}\int_{-1}^{1}\frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{(1-\xi^2)[\lambda^2+(\xi-\nu)^2]}}\right.$$

$$\left.-\frac{1}{l^2}\int_{-1}^{1}\frac{(\xi-\nu)^2(1-\xi)^2}{[\lambda^2+(\xi-\nu)^2]^2}\cdot\frac{d\xi}{\sqrt{(1-\xi^2)[\lambda^2+(\xi-\nu)^2]}}\right].$$

We have now to integrate the above two integrals. For the first integral, making the substitution

$$\xi = \frac{q+y}{1+qy} \quad \text{and} \quad q + \frac{1}{q} = \frac{\lambda^2\nu^2+1}{\nu},$$

we have

$$\frac{2\lambda^2}{l^2}\int_{-1}^{1} \frac{1-\xi^2}{[\lambda^2+(\xi-\nu)^2]^2} \cdot \frac{d\xi}{\sqrt{(1-\xi^2)[\lambda^2+(\xi-\nu)^2]}}$$

$$= \frac{4\lambda^2(1-q^2)^{\frac{3}{2}}}{l^2 \mathrm{A}^{\frac{5}{2}}}\int_0^1 \frac{(1-y^2)(1+q^2y^2)}{(1+my^2)^2} \cdot \frac{dy}{\sqrt{(1-y^2)(1+my^2)}},$$

where m and A have the same meaning as before. Again, substituting for y

$$y^2 = \frac{x^2}{1+m-mk^2},$$

this integral reduces to

$$\frac{4\lambda^2(1-q^2)^{\frac{3}{2}}}{l^2 \mathrm{A}^{\frac{5}{2}}} \cdot \frac{k}{\sqrt{m}}\int_0^1 (1-x^2)(1-a^2x^2) \frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}}$$

where

$$k^2 = \frac{m}{l+m} \quad \text{and} \quad a^2 = \frac{m-q^2}{l+m}.$$

If now we introduce the following notations

$$u_0 = \int_0^1 \frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}}, \qquad u_1 = \int_0^1 \frac{x\,dx}{\sqrt{(1-x^2)(1-k^2x^2)}},$$

$$u_2 = \int_0^1 \frac{x^2\,dx}{\sqrt{(1-x^2)(1-k^2x^2)}}$$

and in general

$$u_n = \int_0^1 \frac{x^n\,dx}{\sqrt{(1-x^2)(1-k^2x^2)}},$$

then the first integral reduces to

$$\frac{4\lambda^2(1-q^2)^{\frac{3}{2}}}{l^2 \mathrm{A}^{\frac{5}{2}}} \frac{k}{\sqrt{m}}[u_0-(1+a^2)u_2+a^2u_4]$$

and the second integral to

$$-\frac{2(1-q^2)^{\frac{5}{2}}(n-q)^2}{l^2 A^{\frac{5}{2}}} \frac{k}{\sqrt{m}}\left[u_0-(1+b^2)u_2+b^2u_4\right],$$

where

$$b^2=-m\frac{a^2}{q^2}.$$

It will be seen that the integral denoted by u_0 is the complete Elliptic Integral of the first order with the modulus k. It is generally denoted by F. The complete Elliptic Integral of the second order with the same modulus is denoted by E. Hence we may write

$$\mathrm{F}=u_0=\int_0^1 \frac{dx}{\sqrt{(1-x^2)(1-k^2x^2)}},$$

$$\mathrm{E}=\int_0^1 \sqrt{\frac{1-k^2x^2}{1-x^2}}\,dx,$$

$$\therefore \quad u_2=\int_0^1 \frac{x^2dx}{\sqrt{(1-x^2)(1-k^2x^2)}}=(\mathrm{F}-\mathrm{E})/k^2.$$

For expressing

$$u_4,\ u_6, \ldots u_{2n}$$

in terms of F and E the following reduction formula will be of use If we put

$$\mathrm{X}=(1-x^2)(1-k^2x^2)$$

$$\frac{d}{dx}\left(x^{r-3}\sqrt{\mathrm{X}}\right)=(r-3)x^{r-4}\sqrt{\mathrm{X}}+\tfrac{1}{2}\frac{x^{r-3}}{\sqrt{\mathrm{X}}}\frac{d\mathrm{X}}{dx}$$

$$=(r-1)k^2\frac{x^r}{\sqrt{(1-x^2)(1-k^2x^2)}}$$

$$-(1+k^2)(r-2)\frac{x^{r-2}}{\sqrt{(1-x^2)(1-k^2x^2)}}$$

$$+(r-3)\frac{x^{r-4}}{\sqrt{(1-x^2)(1-k^2x^2)}}.$$

Integrating both sides of the identity with reference to x between the limits 0 and 1, we have

$$0-(r-1)k^2\int_0^1 x^r \frac{dx}{\sqrt{X}}-(1+k^2)(r-2)\int_0^1 x^{r-2}\frac{dx}{\sqrt{X}}$$

$$+(r-3)\int_0^1 x^{r-4}\frac{dx}{\sqrt{X}}$$

so that

$$(r-1)k^2u_r=(1+k^2)(r-2)u_{r-2}-(r-3)u_{r-4}.$$

We know that

$$u_0=\mathrm{F} \quad \text{and} \quad u_2=\frac{\mathrm{F}-\mathrm{E}}{k^2},$$

and from the above

$$3k^2u_4=2(1+k^2)u_2-u_0$$

$$5k^2u_6=4(1+k^2)u_4-3u_2$$

and so on.

Making these substitutions and after a lengthy series of simplifications we have

$$\frac{1}{\mathrm{R}}=\frac{1}{\mathrm{V}}\left(\frac{\partial w}{\partial y}\right)_0=\frac{\Gamma_0}{2\pi l^2\mathrm{V}}\,\mathrm{P}.\left[\frac{\nu}{q}\tan^2\alpha.\,\mathrm{E}-q\nu(\mathrm{F}-\mathrm{E})/\tan^2\alpha\right]$$

where

$$\log \mathrm{P}=\tfrac{3}{2}[\mathrm{L}\sin\alpha+\mathrm{L}\cos\alpha-\log\lambda-20].$$

Writing this in terms of aeroplane constants

$$\frac{1}{\mathrm{R}}=\frac{\mathrm{C}_a}{\pi^2}\cdot\frac{2}{t}\cdot s^2.\,\mathrm{P}\left[\frac{\nu}{q}\tan^2\alpha.\,\mathrm{E}-q\nu(\mathrm{F}-\mathrm{E})/\tan^2\alpha\right].$$

The quantities C_a , t and s are constants for a wing with a given angle of attack, hence

$$\frac{1}{\mathrm{BR}}=\mathrm{P}\left[\frac{\nu}{q}\tan^2\alpha.\,\mathrm{E}-q\nu(\mathrm{F}-\mathrm{E})/\tan^2\alpha\right].$$

In the expression for $\frac{1}{BR}$ two quantities λ and ν are independent variables. For particular values of λ, we might plot

$$\left(\frac{1}{BR}, \nu\right)$$

curves. These curves have been plotted and published in the Zeitschrift für angewandte Mathematik und Mechanik, 1924. Tables of values of $\frac{1}{BR}$ corresponding to a series of values of λ ranging from 0 to 0·6 and of ν from 0 to 2, have been attached to this publication. We shall have to refer to those tables later on.

Experiments in Wind-channels.

In aerodynamical experiments now-a-days Wind-channels are as common and as useful as Test-tubes are to chemists. But there are two essential differences between them. Experiments in test-tubes are carried on on substances that are part—however small a part they may be—of the original substance, whereas in aerodynamical laboratories experiments are carried on on models that are exact miniatures of originals and, however exact these miniatures may be, their smaller dimensions introduce a scale effect which has to be accounted for. The tendency now-a-days is to construct models as large or almost as large as originals so that this effect might be neglected. This demands the wind-channels to be much larger than they are now. There is another point of difference. Test-tubes must never react on the substances under examination. But the same thing cannot be said of Wind-channels. They do, and that most seriously, react on the experimental results found in them. We shall consider this effect now.

In Wind-channel experiments, as is well-known, the body to be experimented upon is placed in the channel through which a steady current of air is blown or drawn. By various contrivances this current of air is rendered free from eddies and the six components of forces on the body are measured. The qualities that concern wing measurements most are its lift and drag for different angles of attack and the corresponding positions of the centre of wind-pressure. But these

quantities measured in the channel are quite different from the corresponding quantities when measured in free space. We know that the stream-lines generated by a body which is moving in a medium or over which the medium is passing whose boundaries extend to infinity would be quite distinct from those in a limited medium. This fact of Hydrodynamics will have to be taken into account in assigning any particular angle of attack to any lift- and drag-coefficients C_a C_w. In any wind channel experiments with wings what is usually done is that the wing is set at a particular angle of attack (*i.e.*, the angle between the chord of the wing and the direction of the wind, which is usually horizontal, is measured) and its corresponding lift and drag are then experimentally determined. But this geometrically measured angle of attack, it is apparent, is not the same as the real or effective angle. By effective angle we mean that angle which the real stream-lines make with the chord of the wing.

We have already seen before that for a wing in an unlimited medium

$$a_E = a_\infty + \frac{w_0}{V}.$$

The presence of the walls of the channel will limit the extents of the medium, and its influence, it will be broadly seen, will be to introduce a further modification of the above formula. The disturbance due to the channel will consist in superimposing another downwash w'_0 and in giving a curvature to the stream-lines given by

$$\frac{1}{R} = \frac{1}{V}\left(\frac{\partial w'}{\partial y}\right)_0,$$

where y is measured along the stream and the curvature is taken in a vertical plane of a stream-line as it crosses the vertical plane through the wing.

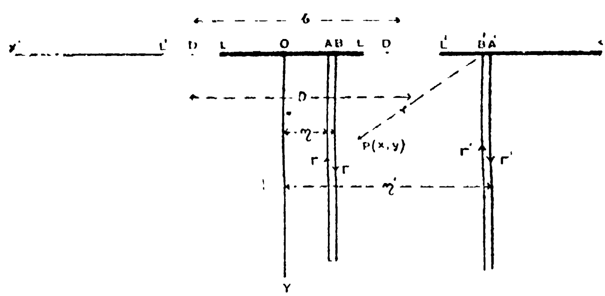
Considering these two influences as before we have

$$a = a_E + \frac{w_0'}{V} + \frac{t}{2R},$$

$$= a_E + \frac{w_0'}{V} + \frac{t}{2V}\left(\frac{\partial w'}{\partial y}\right)_0.$$

To find w' we must replace the wing by the lifting-line with its accompanying vortex system. When this vortex system is placed in

a medium which is bounded by the walls of a wind-channel, we know that the boundary (which is assumed circular here) may be removed and its effect calculated by replacing it by the images of the vortices at the inverse points. The accompanying figure will make it clear. The figure is in the plane of the vortices, which is assumed horizontal. LOL is the wing, O its middle point, D and D are the points of section with the canal, L′ is the point inverse to L with respect to the circle, the inverse vortices extending to infinity along L′X and L′X′, OY is horizontal and taken along the direction of the stream. One vortex Γ enters LOL at A $(\eta, 0)$ and goes out at B $(\eta+d\eta, 0)$, the inverse point B′ also possesses a vortex Γ' coming in and at A′ going out.



We have

$$\Gamma = \Gamma_0 \sqrt{\left(1 - \frac{4\eta^2}{b^2}\right)}$$

$$\Gamma' = \Gamma_0 \sqrt{\left(1 - \frac{4\eta^2}{b^2}\right)}$$

$$= \Gamma_0 \sqrt{\left(1 - \frac{b'^2}{4\eta'^2}\right)}$$

where

$$b = 2l, \qquad b' = \mathrm{L'OL'}$$

w_1 = vertical component of the velocity induced by the vortex at B′ at P(xy)

$$\frac{\Gamma'}{4\pi(\eta' = x)}(1 + y/r).$$

The pair of vortices at B′ and A′ having the same strength Γ' but different rotations produces then a vertical velocity at P which

can be written as the difference of the effect of the two vortices at A′ and B′ which are close together.

$$dw_1 = \frac{\partial w'}{\partial \eta'} d\eta' = \frac{\Gamma'}{4\pi}\left[\frac{1}{(\eta'-x)^2}\left(1+\frac{y}{r}\right)+\frac{1}{\eta'-x}\cdot\frac{y}{r^2}\cdot\frac{\partial r}{\partial \eta'}\right]d\eta'$$

$$= \frac{\Gamma'}{4\pi}\left[\frac{1}{(\eta'-x)^2}\left(1+\frac{y}{r}\right)+\frac{y}{r^3}\right]d\eta'$$

Due to the cross vortex B′A′

$$dw_2 = \frac{\Gamma' d\eta'}{4\pi}\cdot\frac{y}{r^3}.$$

Hence the whole downward induced velocity at P due to the bound and free vortices at B′ and A′ is

$$dw' = \frac{\Gamma' d\eta'}{4\pi}\left[\frac{1}{(\eta'-x)^2}\left(1+\frac{y}{r}\right)+\frac{2y}{r^3}\right]d\eta'$$

$$\therefore \quad w' = \frac{\Gamma_0}{4\pi}\int_{b'/2}^{-b'/2}\left[\frac{1}{(\eta'-x)^2}\left(1+\frac{y}{r}\right)\right.$$

$$\left.+\frac{2y}{r^3}\right]\sqrt{1-\frac{b'^2}{4\eta'^2}}\,d\eta'.$$

Since $y=0$ on the wing where w_0' is taken

$$w_0' = \frac{\Gamma_0}{4\pi}\int_{b'/2}^{-b'/2}\frac{\sqrt{1-b'^2/4\eta'^2}}{(\eta'-x)^2}\,d\eta'.$$

Putting

$$\xi - \frac{2b}{D^2}\,x = \frac{2x}{b'} \quad \text{and} \quad \frac{b'}{2}\chi = \eta' \quad \therefore \quad \chi > 1$$

$$v_0' = \frac{\Gamma_0}{4\pi}\int_1 \frac{\sqrt{1-1/\chi^2}}{\left(\frac{b'^2}{2}\chi - x\right)^2}\cdot\frac{b'}{2}\,d\chi$$

$$= \frac{\lambda}{\pi D^2 \rho v}\left(1+\tfrac{3}{4}\xi^2+\tfrac{5}{8}\xi^4+\tfrac{35}{128}\xi^6+\ldots\right).$$

Again

$$\left(\frac{\partial w'}{\partial y}\right)_{y=0}=\frac{3\Gamma_0}{\pi b'}\int^{-1}\frac{\sqrt{\chi^2-1}}{\chi(\chi-\xi)^3}\,d\chi$$

$$=3\,\frac{\partial w_0'}{\partial \xi}$$

$$=\frac{3A}{\pi D^2\rho V}\left(\tfrac{3}{2}\xi+\tfrac{5}{2}\xi^3+\tfrac{105}{64}\xi^5+\ldots\ldots\right).$$

We have put

$$\xi=\frac{2b}{D^2}x=\frac{4l}{4R^2}x=\frac{l}{R^2}x,$$

where R is the radius of the channel. In ordinary experiments $\frac{l}{R}$ does not generally extend beyond $\frac{1}{2}$, and $\frac{x}{R}$, as the point must be on the wing itself, cannot be greater than 1/2. Hence generally

$$\xi<\tfrac{1}{4}$$

and in w_0' we need not take more than three terms and in

$$\left(\frac{\partial w'}{\partial y}\right)_0$$

more than two.

Thus we have

$$w_0'=\frac{A}{\pi\rho D^2 V}\left(1+\tfrac{3}{4}\xi^2+\tfrac{5}{8}\xi^4\right)$$

and

$$\frac{1}{R}=\frac{1}{V}\left(\frac{\partial w'}{\partial y}\right)_0=\frac{3A}{\pi\rho D^2V^2}\left(\tfrac{3}{2}\xi+\tfrac{5}{2}\xi^3\right).$$

With these the effective angle of attack (α_∞) of a wing in a wind-channel experiment with a measured angle of attack (α) is given by the following relation :

$$\alpha=\alpha_\infty+\frac{w_0}{V}+\frac{w_0'}{V}+\frac{l}{2R}$$

$$=\alpha_E+\frac{A}{\pi\rho D^2V^2}\left(1+\tfrac{3}{4}\xi^2+\tfrac{5}{8}\xi^4\right)+\frac{3Al}{2\pi\rho D^2V^2}\left(\tfrac{3}{2}\xi+\tfrac{5}{3}\xi^3\right),$$

where

$$\xi = \frac{l}{R} \cdot \frac{x}{R}$$

and A, a are found experimentally.

The importance of this formula for transformation will be at once apparent, if we remember that in all wind-channel experiments it is the angle of attack which distinguishes one set of experiments from others. In the above I have not considered the influence of the breadth of the wing, as I have replaced the wing by a line vortex only. The peculiar distribution of vortices over the breadth of the wing that will satisfactorily replace it has been discussed by Dr. Birnbaum in his paper in the Zeitschrift für angewandte Mathematik und Mechanik. In my Dissertation (Göttingen, Das Doppeldeckerproblem, 1923) I have discussed this effect in the case of a biplane, and a corresponding treatment might be adopted in this case. I must wait till some experimental physicist tests how the above formula works.

In practice an average value of a_{∞} over the whole span of the wing must be taken. As a matter of fact, all the formulae found in the preceding pages have two independent variables λ and ν; and on the wing itself they all vary with ν; hence for practical purposes an average value of these quantities must be taken over the span of the wing. For an average of this class of quantities that have been tabulated it is convenient to apply Simpsons' rule for averages. This has been done in my published paper in the Zeitschrift and values of quantities required will be taken from this in the following.

Experimental verification.

In the chapter on "Induced velocity," I have referred to a verification of my theoretical results, and in the chapter on Induced Angle of attack I have referred to another. The relation for effective angle of attack suggested there is much more important and I shall have to carry out some detailed calculations to show that the results deduced from the theory and the results found from experiments are in agreement except in those cases where the effects suggested by Dr. Birnbaum become operative. Experimental data are taken from Tafel 45, Ergebnisse der aerodynamischen Versuchsanstalt zu Göttingen, Lieferung II, 1924.

It has been proved by Prandtl in the above publication that the expression w_0' (see page 26) can be put in the form

$$\frac{w'_0}{V} = \frac{C_a}{\pi}\left(\kappa \frac{F_D}{b_D^2} - \frac{F_E}{b_E^2}\right),$$

where

$$\kappa = \frac{\text{induced resistance of the biplane}}{\text{induced resistance of the monoplane}}$$

and F_D, F_E are respectively the surface area of the biplane and the monoplane wings and b_D, b_E their corresponding spans.

If a_D denote the geometrical angle of attack of the upper wing of biplane and a_E the corresponding quantity for a monoplane, then it was suggested by Prandtl that

$$a_D = a_E + \frac{C_a}{\pi}\left(\kappa \frac{F_D}{b_D^2} - \frac{F_E}{b_E^2}\right).$$

But experiments belied this deduction. In fact, a series of values of κ were found experimentally by measuring a_D and a_E of different biplanes. These experimentally found quantities were denoted by K' (exp.) and the corresponding relation was then written as

$$a_D = a_E + \frac{C_a}{\pi}\left(\kappa' \frac{F_D}{b_D^2} - \frac{F_E}{b_E^2}\right)$$

A series of values of κ' are given in the Table.

The formula used by me is

$$a_D = a_E + \frac{C_a}{\pi}\left(\kappa \frac{F_D}{b_D^2} - \frac{F_E}{b_E^2}\right) + \frac{t}{R}\left(\frac{3}{4} - \frac{C_m}{C_a}\right)$$

where t is the whole breadth of the wing.

The quantity 1/R varies over the whole span of the wing. Hence an average value must be taken over the whole span. We have

$$\left(\frac{1}{R}\right)_m = B\left(\frac{1}{BR}\right)_m = B\frac{\int_0^1 (1-\nu)^{\frac{1}{2}} / BR_0 \,.\, d\nu}{\int_0^1 \sqrt{1-\nu^2}\, d\nu}$$

$$4B\int \frac{\sqrt{1-\nu^2}}{BR}\, d\nu = \frac{4B}{\pi} N$$

where

$$B = \frac{\Gamma_{20}}{2\pi l^2 v} = \frac{4A_2}{\pi\rho v b} \cdot \frac{2}{\pi b^2 v} = \frac{4}{\pi^2} \cdot C_a \cdot \frac{t}{b}$$

N can be found by Simpson's method of finding averages. For values of

$\lambda = h/l$,	0,2	0,3	0,4	0,5	0,6

we find

$\lambda^2 N =$	0,68	0,683	0,682	0,678	0,665

In ordinary biplanes $\lambda = h/l = \frac{\text{distance between two wings}}{\text{half the span of the wing}}$, the wings being taken as equal, varies from 0,3 to 0,5. Hence for this most common type we can take

$$N = 0{\cdot}68\left(\frac{l}{h}\right)^2 = 0{\cdot}17\,\frac{b^2}{h^2}.$$

We may therefore assume

$$\left(\frac{1}{R}\right)_m = \frac{16}{\pi^3} \cdot \frac{C_a \cdot t}{b^2} \cdot 0{\cdot}17\,\frac{b^2}{h^2} = 0{\cdot}0875\, C_a\, \frac{t}{h^2}$$

and

$$a_D = a_E + \frac{C_a}{\pi}\left(\kappa\frac{F_D}{b_D^{\,2}} - \frac{F_D}{b_E^{\,2}}\right) + 0{\cdot}0875\left(\frac{3}{4}C_a - C_m\right)\frac{t^2}{h^2}.$$

The first two terms are the same as Prandtl's; if we denote them by a'_D and calculate

$$\Delta a = a_D - a'_D$$

for two values of

C_a , *e.g.* $C_{a_1} = 0{\cdot}6$ and $C_{a_2} = 0$, a quantity

$$\kappa' = \kappa + \frac{\pi b_D}{F_n} \cdot \frac{\Delta a_1 - \Delta a_2}{C_{a_1} - C_a}$$

can be theoretically deduced and then compared with the experimentally determined κ'. If they agree, they justify the theory, if not, the theory goes.

I have taken the following figures from the Table 45 of the Ergebnisse, before mentioned. They relate to biplanes of equal upper and lower wingspan. The monoplane for which a_D was taken gave for $C_a = 0$, $C_m = 0{\cdot}080$ and for $C_a = 0{\cdot}6$, $C_m = 0{\cdot}268$. The following Table shows that κ' as deduced above theoretically and k' found experimentally by Prof. Prandtl agree quite well.

Nr.	$h:t$	$b^2:F$	κ'(exp.)	$sa_1 - sa_2$	κ'(theor.) $-\kappa$(theor.)	κ(theor.)Prandtl.	κ'(theor.)*Author
1	0,8	3,0	1,211	0,0359	0,563	0,794	1,357
2	1,1	3,0	1,049	0,0190	0,298	0,754	1,042
3	1,4	3,0	0,967	0,01173	0,184	0,721	0,905
4	1,113	2,4	0,949	0,01857	0,234	0,722	0,956
5	1,113	1,44	0,803	0,01857	0,140	0,649	0,789

The small divergences could be accounted for by Dr. Birnbaum's suggestions. I am working out this suggestion to prove complete coincidence.

In the above I have not given any table from which N and other quantities have been taken. They can be found in the Appendix to my paper in the Zeitschrift.

A Comparison Table for κ's

No.	Experimental.	Theoretical.	
		Prandtl.	Author.*
1	1,211	0,794	1,357
2	1,049	0,754	1,042
3	0,967	0,721	0,905
4	0,949	0,722	0,956
5	0,803	0,649	0,789

* My calculated figures.

On the Occurrence of Limnocharis flava Linn. in Burma.

BY

PAUL BRÜHL, D.SC., AND SATYARANJAN SEN, M.SC.

Limnocharis flava is, like *Eichhornia speciosa*, one of the considerable number of phanerogamic species which, indigenous in the warmer regions of America, have found their way, usually by conscious or unconscious human agency, into the tropical and subtropical parts of the Eastern Hemisphere. (*See* Paul Brühl, Recent Plant Immigrants, Journal of the Asiatic Society of Bengal, Vol. IV, pp. 602 (1910), as well as other more recent publications on kindred subjects.)

Limnocharis flava has been reported as indigenous in Brazil, Perú, Ecuador, Venezuela, New Granada, Columbia, Panamá, Nicaragua, Guatemala and the islands of Sta. Martha, San Domingo and Cuba. (*See* Marco Micheli, in De Candolle's Suites au Prodromus, Vol. III, pp. 89-91). FR. BUCHENAU, in Engler, Das Pflanzenreich, IV, 16 (1903), p. 9, states that a variety of *L. flava*, which he publishes under the name of var. L. INDICA, has been found by WARBURG growing in the rice-fields of Java and gathered by R. ZIMMERMANN near Bangkok in Siam. In November, 1925 it was discovered by one of us (S.) growing in a narrow and shallow water channel near the railway station of Hmowbi, about twenty-two miles north of Rangoon; it was also found growing plentifully in shallow water in the rice-fields between Kamayut and Hanthawadi Road station as well in a large tank near Insein. Lastly it has been observed in full flower at the end of January. Its flowering time may be expected to extend well into February, if not even into March.

BUCHENAU defines the genus LIMNOCHARIS as follows :

Flores hermaphroditi. Sepala 3, persistentia, fructum amplectentia. Petala 3, tenera, fugacia. Stamina numerosa, externa sterilia (deficientibus antheris); filamenta complanata; antherae basifixae, biloculares, rima laterali longitudinaliter dehiscentes. Carpella 15 ad 20, verticillata, a latere compressa; styli nulli; stigmata sessilia, extrorsa. Fruticuli verticillati, vix cohaerantes, a latere compressi, semicirculares, membranacei, dorso sulcati, interne dehiscentes.

Semina creberrima, uncinato-curvata, testa crustacea, transversim multicostata, Embryo hippocrepicus.

It has to be noted here that in the Burmese specimens the anthers are not "basifixae," but the point of insertion is somewhat above the base, the filaments narrowing down nearly to a point at their apex and the anther being somewhat versatile, though not conspicuously so. Of still greater importance is the fact that in some specimens no trace of staminodes could be discovered; the case is somewhat rare, but there can be no doubt about it. MICHELI's statement that the anthers are extrorse does not apply to the slit, which, as BUCHENAU correctly states, is truly lateral.

In consequence of the occasional complete absence of staminodes in Limnocharis flava the generic key of the Butomaceae is preferably arranged as follows—

A. Stamens 9, sometimes less.
  (*a*) Latex-vessels absent. Petals persistent. Embryo straight ... BUTOMUS, Linnaeus.
  (*b*) Latex-vessels well-developed. Petals fugacious. Embryo horse-shoe shaped ... TENAGOCHARIS, Hochstetter.

B. Stamens numerous, much more than 9. Embryo horse-shoe shaped.
  (*a*) Carpels 15 or more. Stigma sessile. LIMNOCHARIS, Humboldt et Bonpland.
  (*b*) Carpels 3-6, rarely 8, gradually attenuated into a distinct style ... ... HYDROCLEIS, Richard.

The following is a description of the form found in Lower Burma.

Perennial. The 2-5 leaves form a basal cluster and vary considerably in size and to a certain extent also in shape; the petiole is 15-30 cm. long, the basal sheath gradually narrowing upwards into the triangular apical part; the entire, glabrous and smooth blade of the fully developed leaf is broadly ovate to nearly circular in outline, repand-cordate at the base and very shortly drawn out at the apex, 7·5—18 cm. long and 7·5—13 cm. greatest breadth; the primary nerves are numerous, their number being commonly 15, the 3 middle ones are straight, the outer ones more and more convexly curved, all of them converge towards the tip; the secondary nerves are very numerous and run nearly at right angles to the primary nerves. The flower-bearing axes arise from the axil of the basal leaves; they are triangular in cross-section and about equal in length to the petioles. The inflorescence is cymose, closely imitates an umbel and

consists usually of more than ten flowers, which develop one after another. The flowers are supported by ovate or elliptical-oblong bracts, the outer two of which are the largest, about 16 mm. long and 6 mm. broad, resembling the sepals in size and consistency and in bud embrace the pseudo-umbel ; the inner bracts diminish in size down to 3 mm. in length ; they are membranous. The length of the trigonal pedicels is 2·5—8 cm. ; they increase in thickness upwards and are expanded into wings at the edges, the wings gradually becoming wider upwards. The buds are ovoid-oblong. The sepals are imbricate in bud, of firm consistency, broad-ovate, obtuse, suberect, many-nerved, green, about 16 mm. long and 6 mm. broad. The petals are delicate, broadly ovate to nearly circular, obtuse, slightly longer or shorter than the sepals, yellow, imbricate in bud. The stamens are numerous, commonly 40, free, the outer one or two whorls are usually, but not always without anthers ; the anther-bearing filaments are flat, thin, broadly linear, abruptly contracted below the apex and ending in a point, 6—9 mm. long ; the staminodes are somewhat narrower, diminish in breadth from the base upwards, slightly longer or shorter than the anther-bearing filaments ; the anthers are extrorse, oblong, concavely curved between base and apex, the concavity on the side pointing to the axis of the flower, dehiscing by a lateral slit, coloured yellow, the point of insertion being situated slightly above the lower end of the connective. The ovary consists usually of sixteen carpels, cohering slightly at their bases, laterally compressed, closely packed so as to form a short-ellipsoidal structure ; the stigma is sessile, rather minute, papillose, the stigmas together forming a very short cylindrical assemblage. The ripe carpels form a close-set whorl, are nearly free from each other, laterally compressed, membranous, semicircular in outline, their dorsal surface marked by three narrow longitudinal ridges running close to each other and dehiscing along their ventral suture. The seeds are very numerous, 0·5—1 mm. in length, consisting of two arms one doubled back on the other, connate with each other ; the testa is crustaceous, marked with numerous transverse crested ribs. The embryo is horse-shoe shaped.

A note on the vegetative reproduction and other details will be published at a later date

BOTANICAL LABORATORY,
University College of Science
January, 1927.

EXPLANATION OF FIGURES.

PLATE I.

Fig. 1. The plant with inflorescence and a fruit $\times \frac{1}{2}$
Fig. 2. Base of stem $\times \frac{1}{2}$

PLATE II.

Fig. 1. Pseudo-Umbel $\times \frac{2}{3}$
Fig. 2. Flower $\times \frac{1}{2}$
Fig. 3. Sepal $\times \frac{4}{3}$
Fig. 4. Petal $\times \frac{4}{3}$
Fig. 5. Stamens $\times 4$
Fig. 6. Staminode $\times 4$
Fig. 7. Fruit; sepals pulled back $\times \frac{7}{6}$
Fig. 8. Cross-section through ovary $\times \frac{10}{7}$
Fig. 9. Seed $\times 20$
Fig. 10. Fruitlet $\times \frac{10}{8}$.

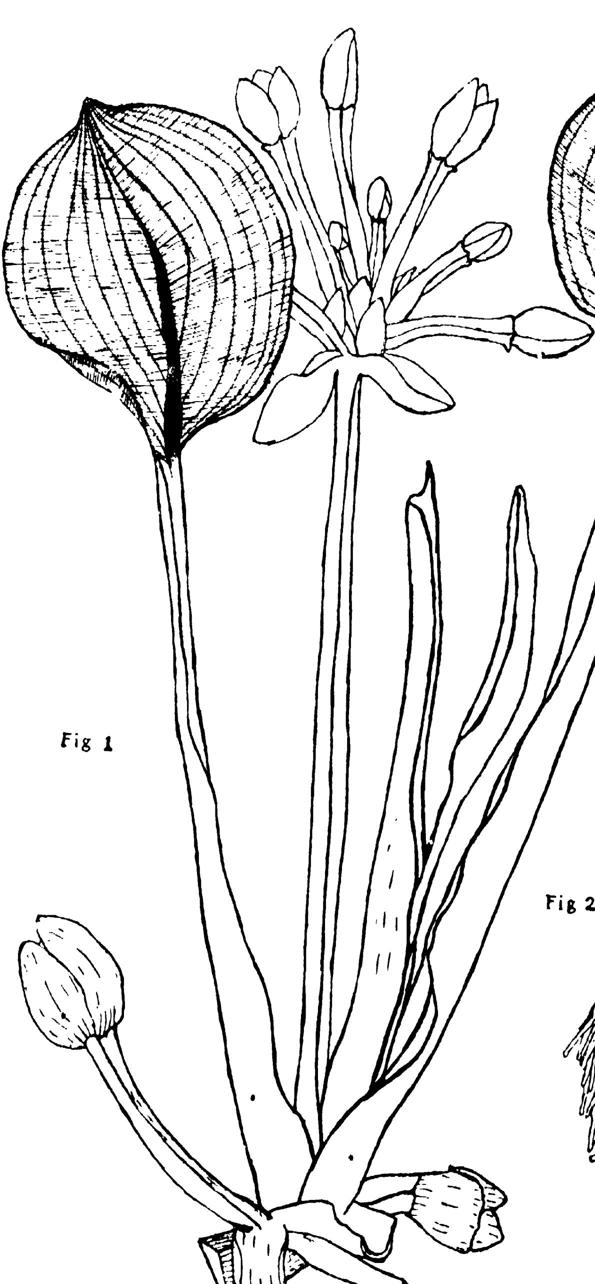


Fig 1

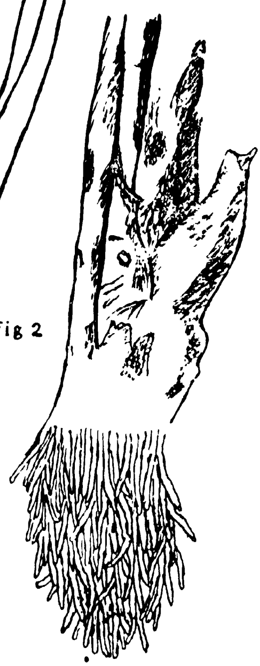


Fig 2

Fig 1

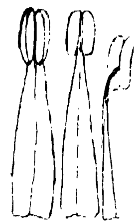


Fig 5

Fig 6

Fig 3

Fig 2

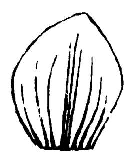


Fig 4

Fig 9

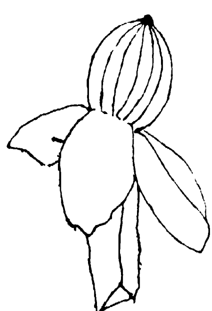


Fig 7

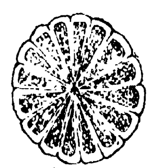


Fig 8

Fig 10

Indian Slime-Fungi (Myxomycetes or Mycetozoa).

FIRST CONTRIBUTION.

BY

PAUL BRÜHL AND JATIS SEN GUPTA.

As far as the Myxomycetes or Mycetozoa are concerned, the greater part of India is yet a *Terra Incognita.* We have therefore decided to make a start with the study of the Indian forms of this interesting group which occupies an intermediate position between the Animal and Plant Kingdoms. Fortunately the splendid Monograph of the Mycetozoa, the first edition of which by the late ARTHUR LISTER appeared in 1894, has been brought up to date by the third edition, edited by GULIELMA LISTER and published in 1925. This work is indispensible to anyone who is interested in the study of Slime-Fungi, and the identification of species is rendered comparatively easy by the accurate descriptions given in the text and the splendidly executed plates. In the following we give a list of the species which may be found in some part or the other of the Indian Empire. The majority of them have been reported from Ceylon and the Indian Archipelago; a number of them are cosmopolitan. The page references are to the third edition of Lister's "Mycetozoa." We mention only Asiatic localities.

CERATIOMYXACEAE.

PAGE

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   Ceylon, Borneo, Japan. Found by us in Bengal, ... 4

PHYSARACEAE

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94. Amaurochaete cribrosa—
Japan 164

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It is highly probable that most of these one hundred and sixty one species will be found within the boundaries of the Indian Empire. In a number of cases in which the distribution as deduced from statements found in botanical literature is rather puzzling, the reason is probably to be ascribed to the incompleteness of our knowledge regarding large portions of the Earth's surface. We only need think of Central Africa, Brazil, and China. The fact that Ceylon, Java and Japan are so frequently mentioned as habitats of mycetozoan species, whilst references to the Indian Empire are remarkably scanty, is simply due to the activity displayed by the botanists of Japan and the members of the botanical staffs of Peradeniya and Buitenzorg. We shall be most grateful for the receipt of specimens of Mycetozoa from various parts of India. The collection of such specimens causes comparatively little trouble—June to September are the months during which Slime-Fungi flourish. For the complete list of the literature on Mycetozoa we may refer the reader to the third edition of Lister's Monograph. We have consulted the following works:—

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ENGLER and PRANTL, Pflanzenfamilien, I. Teil, 1. Abteilung, (1897).

T. MACBRIDE, The North American Slime-Moulds, (1899).

A. LISTER, A Monograph of the Mycetozoa. Second Edition, by GULIELMA LISTER, (1911).

Third Edition, by GULIELMA LISTER. (1925).

DESCRIPTION OF SPECIES FOUND BY US IN BENGAL.

Subclass I. EXOSPOREAE.

Family—CERATOMYXACEAE.

Genus—CERATOMYXA Schroeter.

1. CERATOMYXA FRUTICULOSA (Mueller) Macbride.

Plasmodium usually colourless, growing on decaying wood, giving rise to clusters of sporophores forming cushions, up to 40 mm. and more in length and rather less in breadth having a felty appearance and usually pure-white. Sporophores (in the Bengal specimens) consisting of a stem-like portion 2-4 mm. high and 200-300μ in thickness, dividing upwards into numerous, non-anastomosing branches and branchlets, 0·3 to more than 1 mm. in length and 45-75μ in diameter, forming closely packed entangled tufts; surface of branches and branchlets divided up into a great number of irregularly polygonal often subfusiform areoles with rather feebly marked boundary lines and bearing about their middle, on slender-conical, pointed stalklets, ellipsoidal or obovoid spores. Spores colourless, 8·5—13·5μ in length and 6·5—10μ in diameter; contents granular.

Subclass II. ENDOSPOREAE.

Order I. AMAUROSPORALES.

Spores, as seen under the microscope in transmitted light, violet-brown or purplish grey.

Suborder I. CALCARINEAE.

Sporangia with calcium carbonate in the form of granules or minute crystals.

Family—PHYSARACEAE.

Calcium carbonate in the form of minute granules.

Genus—PHYSARUM, Persoon.

Capillitium a network of delicate threads with vesicles filled with calcium carbonate granules; sporangia subglobose or lenticular or forming plasmodiocarps; capillitium without free hooked branchlets.

1. PHYSARUM TENERUM REX. (1890).

G. Lister, p. 31, plate XXV.

Plasmodium yellow. Total height of fruiting body 1—2 mm. Sporangia globose, stalked, erect or nodding, 0·4—0·5mm. in diameter, yellow; sporangial wall membranous; lime-granules roundish, somewhat scattered, but comparatively close-set. Stalk slender, subulate, ending in a fine point, 0·7—1·2mm. long, straw-coloured. Columella absent. Threads of capillitium very thin and delicate, flexuous, hyaline, branched, the branchlets usually not anastomosing, with adhering numerous irregularly rounded, more or less ellipsoidal, yellowish lime-knots, 11-20μ, in length and 4-13μ in width. Spores spherical, brownish-pink, smooth, contents granular.

On the bark of a dead tree in Pargauna Bikrampur, District of Dacca; collected in July.

Physarum tenerum has been reported from Ceylon, Borneo, Japan, Europe, the West Indies and North and South America.

2. PHYSARUM MELLEUM, Massee.

G. Lister, p. 25, plate XXIII.

Plasmodium yellow. Height of fruiting body 0·7-0·9 mm. Sporangia globose, stalked, errect, oblate-spheroidal to spherical, 0·37-0·5 mm. in diameter, yellow to brownish-yellow; sporangial wall irregularly and closely wrinkled, the ridges yellow, the depressions appearing darker, the lime-granules yellowish, rather closely set. Stalk 0·4-0·5 mm. long, nearly terete, 100-120μ in diameter near its base, narrowing down to 60-80μ upwards, furrowed, white, impregnated with calcium carbonate. Columella very short, rounded-subconical. Threads of capillitium irregularly branching, rather slender, hyaline, freely anastomosing, often expanded at the axils, with adhering irregular lime-knots of various shape and size, mostly conspicuous and rather angular, 17-20μ long, 10-12μ wide, white or white with a yellowish tinge. Spores purplish-brown, nearly smooth, 7-10μ in diameter.

On rotting leaves of *Cocos nucifera* in Baliganj. Collected in July and August.

Physarum melleum has been reported growing on dead wood in Europe, the United States, Japan, South Africa and South Australia and is said to be abundant throughout the Tropics.

3. PHYSARUM ECHINOSPORUM, Lister.

G. Lister, p. 57, plate LIII.

Sporangia (in the Bengal specimens) mostly in the form of plasmodiocarps; plasmodiocarps irregularly sinuous, strongly laterally compressed, usually nearly of the same width from base to apex, sometimes slightly thicker at the base, the top-ridge forming a very acute angle, height 1 mm. and more, but commonly less, distance between extremities 1-10 mm.; sporangial wall double, outer densely impregnated with calcium carbonate, white, egg-shell-like, separable from the inner wall; inner membrane pale-purple, shining and iridescent. Capillitium consisting of hyaline threads with comparatively large, close-set, irregularly shaped, white lime-granules 50-160μ long and 10-70μ wide, the granules being connected by short, comparatively stout capillitium threads. Spores spherical, 8-16μ in diameter, purplish-brown, beset with numerous short, stout, truncate spinules.

On dead leaves of *Mimusops Elengi* in the Botanical Garden attached to the Biological Laboratory, Baliganj, collected in August.

This species is of interest as having been previously reported only from the island of Antigua, where it was found growing on dead leaves.

Genus—DIDERMA, Persoon.

Capillitium without lime-knots. Sporangia stalked or sessile or forming plasmodiocarps; sporangium-wall in nearly all species consisting of two layers containing deposits of calcium carbonate. Columella usually present. Threads of capillitium simple or branched.

1. DIDERMA EFFUSUM, (*Schweinitz*) Morgan.

G. Lister, p. 85, plate LXXXIII.

Sporangia sessile, single forms rather scarce, depressed globose, usually united into elongated, somewhat flattened, winding, simple or branched or ring-shaped, free or anastomosing plasmodiocarps, 0·4-0·8 mm. broad, of various length, sometimes effuse and then considerably wider; sporangial wall consisting of an outer crust which is continuous but fragile and consequently traversed by cracks; crust pure chalk-coloured, consisting of closely packed

granules of calcium carbonate; the inner layer of the sporangial wall formed of a thin, colourless membrane. Columella (in the Bengal specimens) practically absent (in foreign specimens stated to be depressed cushion-shaped, brownish-flesh-coloured, and enclosing lime-granules). Capillitium consisting of delicate, colourless, hollow, simple or very sparingly branched threads. Spores spherical or nearly so, smooth, light violet-brown, 6-10μ in diameter.

On rotting palm leaves in a nursery in Baliganj. Collected in August. Reported from Ceylon, Java, Japan, various European localities, the United States and Argentina.

Genus—TRICHAMPHORA.

Sporangia saucer-shaped or umbrella-shaped, on a dark-reddish or light-brown stalk; sporangial wall membranous, impregnated with granules of calcium carbonate, capillitium of colourless branching threads with few or many lime-knots or membranous tubes filled with lime, or without any lime deposit.

1. TRICHAMPHORA PEZIZOIDEA, Junghuhn.

Plasmodium often extensive, greyish-white. Fruiting bodies gregarious, often very numerous. Sporangia stalked, before the discharge of the spores greyish-white, after discharge pure-white, disk more or less saucer-shaped, the upper surface being somewhat concave, the lower surface correspondingly convex, 0·8—1·3 mm. in diameter, 0·15—0·5 (—0·4) mm. in thickness; circumference circular, dehiscing along the edge; sporangial wall membranous, white from uniformly distributed particles of calcium carbonate; parts of the wall forming the lower surface more coherent and consequently more permanent, after dehiscence resembling the top of a Japanese sun-shade with a minutely ragged edge, whilst the upper surface breaks up, sooner than the lower surface, into minute scales which for some time adhere to and are supported by the outer fringe of capillitium threads; the sporangial wall finally disappears except a few remnants adhering to the tip of the stalk. Stalk awl-shaped, 1—2. 5 mm. long, 300—350μ, thick at the base, 45—60μ thick at the apex, longitudinally striated, light-brown, translucent. Capillitium consisting of a great number of moderately branching and scantily anastomosing colourless, hyaline threads extending from the lower to the upper surface, moderately swollen

at their two ends and at the points of ramification. Spores sperical, 9-11 (—17)μ in diameter, dark or purplish-brown, in the Bengal specimens, as far as seen, smooth, according to Lister "spinose. spinulose, or nearly smooth."

On the bark of part of a tree-stem used as a fence-post in Baliganj. Collected in August.

Also reported from Ceylon, various parts of Europe, and from Japan and Natal; abundant throughout the Tropics.

Family—DIDYMIACEAE.

Calcium carbonate deposits in the form of crystals or disk-shaped aggregates distributed over the sporangial wall; capillitium in nearly all species without lime-knots; sporangia mostly simple, only in the genus *Mucilago* fused into an aethalium.

Genus—DIDYMIUM Schroeder.

Sparangia single; calcium carbonate crystals stellate, either scattered over the surface or combined into a crust.

1. Didymium Clavus, Rabenhorst.

Fruiting bodies 0·5—1·0 mm. in height, not closely crowded, often roughly arranged in rows when arising from the space between two veins. Sporangia disk-shaped, stalked, inserted at right angles to the stalk, circular in outline, 0·5—1·0 mm. in diameter, 0·15—0·20mm. in thickness, white, often with a tint of grey; sporangial wall membranous, spotted brown, beset superficially with stellate crystals of calcium carbonate; a circular area around the point of insertion thicker and dark-brown stalk cylindric, straight, erect, longitudinally ridged and furrowed, 0·1—0·7 mm. long, 0·06—0·2 mm. thick, brownish-black, without calcium carbonate crystals. Columella proper absent. Capillitium consisting of numerous, somewhat sinuous, closely packed, simple or scantily branched, rather rigid, reddish-brown (or colourless) threads. Spores spherical, 5·5—7·5μ in diameter, smooth, reddish-violet.

On dead leaves of *Cocos nucifera* in Baliganj. Collected in July and August. Widely distributed through temperate and tropical regions; in particular reported from Ceylon, Sumatra, Java, Borneo, the Philippines, Tahiti and Madagascar.

Suborder II.—AMAUROCHAETINEAE

Sporangia without calcium carbonate; capillitium and spores darkbrown or violet-brown, rarely ferruginous or colourless.

Family.—STEMONITACEAE.

Sporangia stalked; sporangial wall delicately membranous; at least the upper part of the stalk solid and projecting into the sporangium as a columella; the branching threads forming the capillitium arising from the columella.

Genus—COMATRICHA, Preuss.

Sporangium wall evanescent; threads of capillitium usually forming a network, but not forming an even surface net.

1. COMATRICHA LAXA, Rostafinski.

G. Lister, p. 143, plate CXXII.

Plasmodium white. Fruiting bodies rising from a membranous, brown and shining hypothallus, gregarious or scattered, 2—3 mm. in height. Sporangia shortly cylindric (to globose), obtusely rounded; sporangial wall evanescent. Stalk filiform, thicker towards the base, (0·2—) 0·5—1·2 mm. long, on an average 30—50μ thick, black. Columella reaching nearly to the apex of the sporangium. Capillitium lax to somewhat dense; primary threads arising from various points all along the columella, thinning out from base to apex, at first straight, but finally variously sinuously curved, emitting numerous very slender thread-like anastomosing branchlets woven into a dusky-grey network and terminating in short free ends. Spores spherical, 6·5—9 (—13)μ in diameter, brownish-purple, very minutely and closely spinulose. On the bark of dead trees in Bikrampur, Dacca District. Collected in July, August and September.

Reported from Malaya, Japan and various localities in Europe and the United States.

2. COMATRICHA IRREGULARIS, Rex.

G. Lister, p. 149, plate CXXII.

Fruiting bodies arising from a membranous, brown and shining hypothallus, densely crowded, in the Bengal specimens 8—10mm. high. Sporangia stalked, cylindrical, 4—5mm. in length.

0·25—0·4mm. in diameter at the base, attenuated upwards; sporangial wall evanescent. Stalk slender, (1-3-)—4-5 mm. long, 40-60μ thick, black. Columella straight or slightly flexuose, reaching nearly to the apex of the sporangium, brownish-black. Primary thread of the dusky brownish-grey capillitium arising from various points of the columella, rather stout, thinning out upwards and giving rise to numerous anastomosing slender fine, thread-like branchlets forming an irregular net terminating in free ends. Spores spherical, 7-8 (—10)μ in diameter, covered with brownish-purple, closely set spinules.

On wooden posts in Baliganj, collected in August and September. Reported from Malaya, New South Wales, Canada and the United States.

Genus—LAMPRODERMA, Rostafinski.

Sporangium wall somewhat persistent as an iridescent membrane; capillitium consisting of branching anastomosing threads radiating mostly from the upper part of the columella.

1. LAMPRODERMA SCINTILLANS, Morgan.

G. Lister, p. 153, plate CXXA.

Fruiting bodies 1—1·5 mm. in height, rising from a small, brown hypothallus, numerous, somewhat scattered, arranged along the nerves and nervelets of the pinnae of palm leaves. Sporangia stalked, globose, 0·3—0·5mm. in diameter, bronze-coloured (or red or steel-blue), iridescent sporangial wall thin-membranous, colourless, breaking up into patches which at first stick to the capillitium, but finally disappear entirely. Stalk straight, erect, 0·7—0·8mm. long, 15-45μ thick, slightly broader towards the base, deep-brown to black. Columella subcylindric, rounded at the tip, scarcely reaching the middle of the sporangium. Capillitium of rigid threads radiating from the upper end of the columella, falsely dichotomously branched and more or less anastomosing; branchlets of brownish tints, paler towards their base, attenuated upwards. Spores spherical, 6·5—8μ in diameter, minutely warted, pale-violet.

On decaying palm leaves used in Baliganj as covers of green-houses in nurseries or as fencing. Collected in July and August.

Reported to occur on dead leaves, twigs and straw in Ceylon, Singapore, Java, England and the United States.

Order II—LAMPROSPORALES.

Spores variously coloured, but not violet-brown or purplish-grey.

Suborder—CALONEMINEAE.

Capillitium formed of a system of uniform or sculptured threads.

Family—TRICHIACEAE.

Capillitium consisting of tubular threads branching at wide angles, or free and usually unbranched, thickened by spirals or complete rings.

Genus—TRICHIA, Haller.

Capillitium abundant, consisting of free threads (elaters), pointed at each end, thickened with two to five spiral bands.

1. TRICHIA OPERCULATA, sp. nova.

Fruiting bodies densely crowded, commonly in contact, not rarely adhering along their side-walls, usually leaving triangular or quadrangular spaces at the corners, in cross-section resembling the medullary tissue of phanerogams. Sporangia sessile or very shortly stalked, short-cylindrical or bell-shaped, when separate from their neighbours circular in cross-section, when crowded polygonal, usually pentagonal or hexagonal at their mouth after dehiscence, opening by a moderately convex lid. Capillitium ultimately conspicuously protruding from the open mouth as a woolly mass. Height of sporangium 0·6 —1 mm., diameter 0·4 0·5 mm.; sporangium wall cartilaginous, finally brittle, somewhat furrowed at the base, reddish-brow. Capillitium consisting of flexuous, orange-red, 4—6μ thick, free but variously entangled threads, with very fine thickenings forming about four long drawn-out spirals irregularly and sparsely beset with thin and sharply pointed spicules, often also with minute knob-like swellings, particularly below the pointed ends. Spores spherical or nearly so, the wall copiously beset with minute spicules, but not reticulated, 9—11μ in diameter, pale-yellow, highly magnified nearly colourless.

On decaying bases of the petioles of palms in Baliganj.

Collected in March after a fall of rain.

The new species has some characters in common with *Trichia favoginea*, but the spiral thickenings of the elaters are very narrow and the spirals are long drawn out; the most important difference

being the absence of reticulations on the spores and the smaller si of the latter (9—11μ instead of 13-15μ). From *Trichia contorta* new species is distinguished by its cylindrical or bell-shaped, not subglobose, and densely crowded, often more or less adhering sporangia; from all the other species of *Trich* it differs by its well defined lid, which distinguishes it specially from *Trichia contorta*.

Genus—HEMITRICHIA, Rostafinski.

Capillitium a more or less elastic network of branching threads; threads thickened with two to six spiral bands.

1. Hemitrichia Karstenii, (Rostafinski) Lister.

G. Lister, p. 223, plate CLXVI.

Sporangia sessile, subglobose, scattered, in the Bengal specimens always forming elongated, variously curved, wormlike plasmodiocarps, 0·25—0·4 (—0·5) mm. in width; sporangium-wall firm, cartilaginous, yellow-orange (or yellowish-brown); surface shining, minutely and confusedly wrinkled. Capillitium a somewhat loose network of branching, brownish or greyish-yellow threads (3—) 4·4—6·6μ thick, marked with several very fine spiral bands very sparsely beset with short, thin and pointed spinules; turns of spirals close; the threads with free ends and with swellings below the free ends as well as at the points of branching. Spores spherical or nearly so, (9—) 11—15μ in diameter, yellow, minutely and copiously warted.

On the fibres of decayed leaf-stalks of palms. Collected in August.

Reported from Ceylon, Japan, various European localities and the United States.

Family—ARCYRIACEAE.

Capillitium a network of tubular threads branching at wide angles, smooth or thickened with cogs or half-rings (only in one species indigenous in Portugal with complete rings) spines or warts.

Genus—ARCYRIA, Wiggers.

Sporangium-wall evanescent above, persistent below and there forming a membranous cup; stalk filled with cells looking like spores; capillitium a more or less elastic network.

1. ARCYRIA FERRUGINEA, Sauter.

G. Lister, p. 220, plate CLXXIII.

Fruiting bodies densely crowded, 1—2 mm. in height. Sporangia stalked, ovoid, 0·7—1·3 mm. long, 0·5—1 mm. in diameter, red, orange-coloured to yellow; sporangial cup funnel-shaped, shining, reticulated on the inner surface. Stalk terete, 0·3—0.8 mm. long, red, rising from a hypothallus. Capillitium a network of branching, reddish-yellow or pure-yellow threads marked with transverse bars arranged in a lax spiral. Spores pale-red, closely beset with minute warts, 8—11μ in diameter.

On rotting palm stems and bambus used as posts in Baliganj. Collected during the Rains.

Reported from Ceylon and widely distributed in temperate regions.

2. ARCYRIA CINEREA, Persoon.

Fruiting bodies solitary, gregarious or clustered, 1—3 (0·8—4) mm. in height. Sporangia cylindrical, more rarely ovoid, 0·8—2 mm. long, 0·4—1 mm. in diameter, stalked, dull-yellow (or pale-grey, greenish or bluish-grey or greyish-flesh-coloured); sporangium-wall forming a cup, membranous, minutely papillose, plaited at the base, stalk terete, 0·3—1 (0·2—2) mm. long, 0·05—0·15 mm. thick, pale-brown, consisting of a tubular wall filled with spore-like cells. Capillitium forming a close network of anastomosing, yellowish-grey, spinulose (or warted or banded threads, the upper and middle portion 2—4μ, the basal portion 3—6μ thick. Spores spherical, 6—9μ in diameter, the surface beset with somewhat remote warts, almost colourless shading into dirty-white.

On rotting leaves and stalks of palms in Baliganj. Collected in August.

Widely distributed in the Tropics; reported from Ceylon, Borneo, Japan, Australia, New Zealand, Polynesia, Canada, the West Indies, Central and South America, the United States and various places in Europe.

3. ARCYRIA DENUDATA (Linn.) Wettstein.

G. Lister, p. 235, plate LXXIV.

Fruiting bodies gregarious, crowded, 2—4 mm. in height. Sporangia short-cylindrical or ovoid, 1·5—2 mm. long, 0.8—1 mm.

in diameter, stalked, crimson changing to brown; sporangial wall membranous, evanescent except a basal, plaited and faintly reticulated cup. Stalk slender, terete, furrowed, 0·5—1·5 mm. long, 75—100μ thick, dark-brown. Capillitium forming a dense network of terete, 2—5μ thick, reddish-orange or orange-red threads rising from the cup, without free ends, beset with cog-like minute protuberances disposed irregularly or forming more or less well-developed spirals.

On dead wood, dead branches and sticks and leaves, abundant in Bikrampur, Dacca and Baliganj. Collected in July and August.

Reported from Ceylon, Singapore, Java, Borneo and the Philippines; abundant in temperate and tropical regions.

4. ARCYRIA INSIGNIS, Kalchbrenner and Cooke.

G. Lister, p. 236, plate CLXXXI.

Fruiting bodies gregarious or clustered in scattered crowded groups, 0.5—2 mm. in height. Sporangia very shortly stalked, short-cylindric to ovoid, 0·6—1·8 mm. long and 0·25—0.5 mm. in diameter; cup of sporangial wall membranous, plaited, smooth or spinulose. Stalk thickened upwards, furrowed, 0·2—0·5 mm. long, red, hollow, filled with spore-like cells. Capillitium forming a close network of pink or pale-brownish delicate threads attached to the wall of the cup, 2—4·5μ thick, flat, marked with narrow bands (or with spinules) forming a lax spiral. Spores spherical, nearly smooth, 6—8μ in diameter, under the microscope nearly colourless.

On bambu posts in Baliganj. Collected in August.

Reported from Ceylon, Malaya, Java, Japan, various parts of Europe, the United States, Brazil and Southern Australia.

BOTANICAL LABORATORY,
UNIVERSITY COLLEGE OF SCIENCE,

Baliganj, Mar 1927.

Notes on the Geology of the Island of Bombay.

BY

HEM CHANDRA DAS-GUPTA, M.A., F.G.S.

(with Plate I.)

The present short note is based upon the few geological observations that I could make round about Bombay during my short stay in the City in connection with the sitting of the Indian Science Congress in the year 1926. A comprehensive account of the geology of Bombay was published by Wynne in 1866.[1] Any one who makes a reconnaissance in the City will at once see that some of the observations of Wynne have to be modified and this is my only excuse for drawing up this note.

Wynne gave the following table regarding the arrangement of the rocks in the island of Bombay :—

	7. Alluvium, sand and recent conglomerate.
Tertiary, probably Eocene	6. Basaltic trap dykes.
	5. Fossiliferous fresh-water beds or shale series.
	4. Amygdaloidal trap passing into solid gray trap and containing a band of breccia, and perhaps also the white trap of Dharavee.
	3. Gray trap associated with fresh water beds, shales and flags.
	2. Trappean breccia of Sion Hill, etc.
	1. Black basaltic rock of Seoree, etc.

The rocks (1 to 6) belong to the Deccan trap series and are, accordingly not Tertiary, as they were believed to be at the time of the publication of Wynne's paper, but, as it is well known, their Upper cretaceous age has been definitely established. My remarks will be confined chiefly to the divisions 1, 2, and 4.

[1] Mem. Geol. Surv. Ind., Vol. V, pp. 173-225, 1866.

I will start with the division No. 1. The rocks of this group are very peculiar and developed at two localities near the town of Bombay, namely, at Antop and the Seoree Fort Hill. Though, in the text, the rock was described by Wynne as a 'black basaltic' rock, in the map accompanying his paper, it is described as the 'black rock of Antop hill? Felstone.' It appears that the first mention of this rock was by Dr. Buist[2] who was followed by Dr. Carter.[3] Dr. Buist described the rock as 'a Lydian stone, a black jasper or chert,' while according to Dr. Carter it is a 'black jaspideous rock.'

Mr. Wynne seemed to be very doubtful regarding the nature of this rock and this is quite clear when his description of the rock is examined. General McMahon described this rock as 'subvitreous lava' without assigning any special name to it[4] and since then no work has been done in connection with this. The rock occurs forming a ridge and, as shown in the hand-specimen, is very compact, dark-coloured and splintery. It has a marked conchoidal fracture and is traversed by very small cracks. It is remarkably fresh when compared with the basaltic rocks of the neighbourhood. The specific gravity of the rock was found to be ranging between 2·72 and 2·80.

The microscopic character of the rock has been described by McMahon and, according to his description, it is a very fine-grained volcanic rock without any glassy base but with microscopic grains of triclinic felspar, augite and magnetite. Mention is also made of the presence of porphyritic crystals of triclinic felspar and augite and of opal filling up round holes. I must confess that I have not been able to follow this description throughout. In the first place, the slides do certainly show round holes as mentioned by General McMahon, but I failed to find out the opal occurring as filling up the holes and, as far as I could make out, the holes are filled up by grains of quartz. The rock is composed primarily of a cryptocrystalline base consisting chiefly of small grains of quartz and a dark gray opaque substance with lath-shaped microlites of plagioclase felspar. In this base are to be found grains of quartz filling up the holes as already mentioned, crystals of plagioclase felspar and augite, as also parts of a groundmass very commonly associated with a basalt or a dolerite. Iron ores are also present.

[2] Tran. Bom. Geogr. Soc., Vol. X, p. 174, 1852.

[3] Journ. Bomb. Br. Asiat. Soc., Vol. IV, p. 196, 1852.

[4] Rec. Geol. Surv. Ind., Vol. XX, pp. 107-108, 1887.

A reference to the previous literature shows that, according to the authors who have studied this rock, its origin is rather puzzling, but the detection of the phenocrysts of plagioclase and of augite with remnants of a basaltic or a doleritic groundmass appears to offer the clue to the solution of the problem. It appears that these rocks are nothing but silicified basaltic lavas, the phenocrysts of felspar and augite and the detached portions of the groundmass found here and there representing those parts of the rocks which have escaped silicification. The fresh and compact nature of the rocks shows that the metamorphic agent which is responsible for this silicification could not have been a meteoric one. Wynne's memoir contains an analysis of the Seoree rock, while Dr. Washington has published the analysis of a basalt from the neighbourhood of Seoree.[5] The results of these two analyses are placed side by side for the purpose of comparison.

	I	II	
SiO_2 ...	52·98	61·60	
Al_2O_3 ...	14·53	27·12	
Fe_2O_3 ...	3·38	2·12	
FeO ...	10·05	4·60	
MgO ...	3·66	......	
CaO ...	7·49	2·10	
Na_2O ...	3·43	tr.	
K_2O ...	1·34	tr.	
H_2O ...	1·88	2·46	(loss, *i.e.*, water and organic matter).
H_2O ...	0·48	......	
TiO_2 ...	0·62	n.d.	
P_2O_5 ...	0·64	n.d.	
Cr_2O_3 ...	n.d.	n.d.	
MnO ...	0·04	trace.	
	100·52	100·00	

N. B.—I. Basalt obtained between Race Hill and Seoree, Island of Bombay. (Washington).

II. Seoree rock. (Wynne).

A study of the two analyses brings out that compared with the basalt of the area, the Seoree rock is (1) richer in SiO_2 and Al_2O_3

[5] Bull. Geol. Soc. Amer., Vol. XXXIII, p. 774, 1922.

and (2) poorer in Fe_2O_3, FeO, MgO, CaO, K_2O and Na_2O. A reference to the geological map of Bombay shows that rocks of the type, under discussion here, are developed in a straight line beginning from the neighbourhood of Doonoree in the N.N.E. and ending with the Cross island in the S.S.W., a distance of some 6 miles.

It has been well established that the basalt of the Deccan trap came out through many fissures and it is very likely that the line outlined above showing the distribution of the silicified rocks is one such fissure. An instance of a silicification of a basaltic flow from Hyderabad has been studied by Mr. Hallowes [6] and, in this case, the author, after following Drs. Fermor and Fox, has concluded that in this silicification the primary agent was meteoric water bearing CO_2 and containing in solution SiO_2 and CaO leached from the Deccan trap. I have already given my reasons for demurring to this hypothesis of the meteoric water and am inclined to believe that the silification was carried on by magmatic water containing SiO_2 in solution.

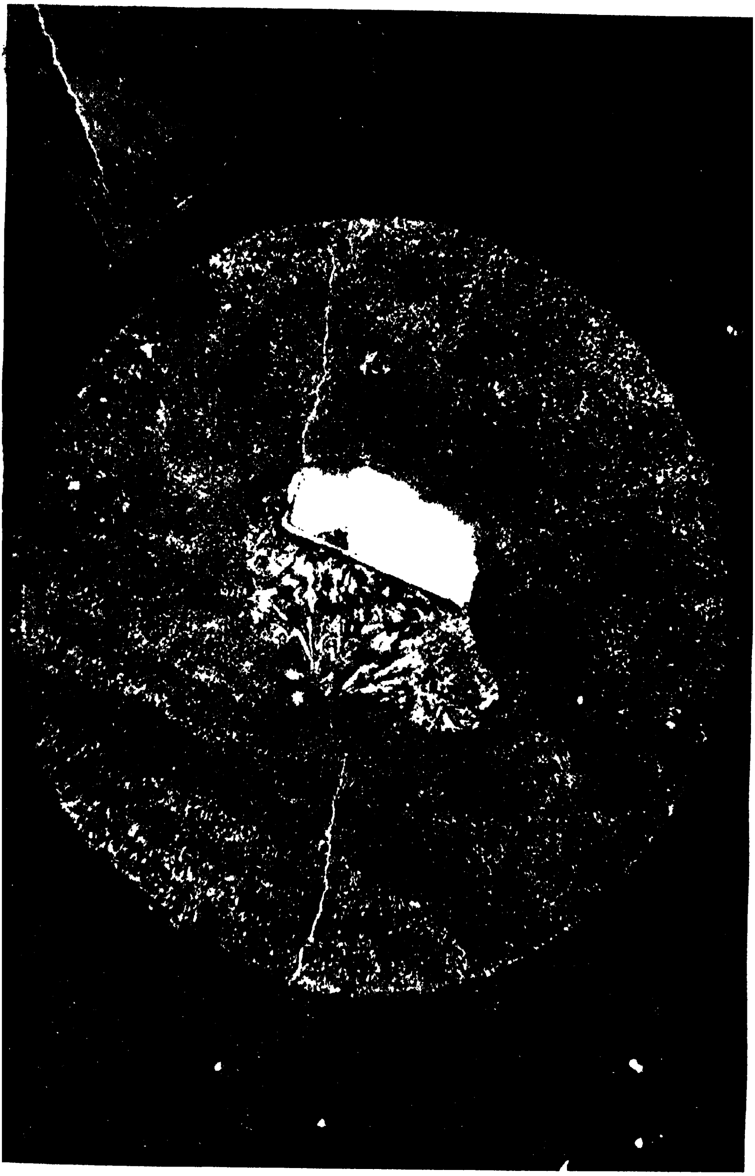
The cooling of lava is an extremely slow process chiefly due to the fact that the upper layers of the cooled lava are usually very bad conductors of heat, and thus it is quite possible that the magmatic water containing SiO_2 in solution was rising upwards and gradually attacking and replacing the already consolidated portions of rocks. Reference may be made in this connection to the recently published paper of Dr. Fermor in which palagonitisation and serpentinisation are supposed to be due to magmatic water.[7] Attention may also be drawn to a case in which Sir Thomas Holland [8] described the alteration of a peridotite by water and carbonic acid which were 'originally included in, and uniformly distributed in sufficient quantity through, the magma,' so that in this case 'The consolidation of the rock and its alteration were, if the phenomena have been correctly read, continuous.'[9]

6 Rec. Geol. Surv. Ind., Vol. XLIX, pp. 220-222, 1918.

7 Rec. Geol. Surv. Ind., Vol. LVIII, pp. 93-240, 1925.

8 Mem. Geol. Surv. Ind., Vol. XXXIV, pp. 1-9, 1901.

9 Reference may be made, in this connection, to the case of the silicification detected in the case of the recent volcano of the Koh-i-Sultan in Baluchistan by the late Mr. Vredenburg, according to whom 'silicification has also taken place in some localities. Superheated vapours charged with silica have found their way through vertical cracks and little by little the substance of the rock has been replaced by silica, causing the altered portion to resist weathering better than the unaltered rock, so that it stands out resembling a dyke.' (Mem. Geo. Surv. Ind., Vol. XXXI, p. 279, 1901.)



'hotomicro by Maitra.

Silicified basalt × 18

a = Plagioclase phenocryst.

b = Basaltic groundmass.

Division No. 2 is next to be dealt with. The rock included in this group is exposed at several places in the area, but the section exposed on the eastern side of the Sion Fort Hill shows its nature unmistakably and proves that the so-called trappean breccia is nothing but a lateritic decomposition product of the underlying basalt.

The white trap of Dharavee (No. 4) is white to brown in colour and considerably decomposed. There are two specimens of this rock in my possession, one presented by Mr. Ribero and the other collected by myself. Both of them are weathered, only one more than the other. The specific gravity of the rock is 2·30. When studied with the help of a microscope, the porphyritic nature of the rock becomes at once clear. The phenocrysts are chiefly orthoclase with plagioclase in a holocrystalline groundmass mainly composed of plagioclase. Quartz is also found in the groundmass, but taking into consideration the extremely decomposed nature of the rock, it is difficult to say if the grains of quartz are wholly secondary or partly secondary and partly original. The slide also shows copious iron-ores, black and brown to yellowish-brown in colour. They may be taken to have been derived from the decomposition of some ferromagnesian silicates but no traces of these minerals appear to have been left. Dr. Fox has in his possession specimens of syenite-porphyry obtained from a place called Kharodi. In course of a discussion I had with him regarding the nature of the Bombay rocks he very kindly drew my attention to the syenite-prophyry in his collection and the remarkable similarity between his specimens and the specimens collected by me from Dharavee. The specimen of Dr. Fox is more fresh but it also does not show the presence of any ferro-magnesian constituent. In his work dealing with the basaltic rocks of Bombay McMahon pointed out the presence of primary magnetite in them [10] and there is nothing to prevent us from attributing the magnetitic iron-ores of this rock to the same source while the brown to yellowish brown oxides of iron may be looked upon as having been derived from the primary magnetite. The change in this case is one chiefly of hydration and, according to Van Hise, may be expressed by the following equation :—

$$4\ Fe_3O_4 + 2\ O + 9\ H_2O = 3\ (2\ Fe_2O_3 . 3\ H_2O) + K$$

In his elaborate study of the Bhuswal section of the Deccan trap Dr. Fermor [11] has distinguished between two types of primary

[10] Rec. Geol. Surv. Ind., Vol. XVI, pp. 42-50, 1883.

[11] Rec. Geol. Surv. Ind., Vol. LVIII, p. 196, 1925.

iron-ores, (i) 'occurring mainly in granules with bars,' and (ii) 'usually in bars only' as being present in it and the iron ores found in this rock are of the granular pattern described by Dr. Fermor. The granules of iron-ore appear to encroach on the crystals of plagioclase in a manner indicated by Dr. Fermor.

The Dharavee specimens come from a definite horizon, namely that underlying the fresh-water frog-bearing beds and it is not known whether the Dharavee exposures are contemporaneous with the rock from Kharodi which is 4 miles west of the Malad Railway Station and at distance of about 10 miles from Dharavee. The Dharavee exposure, however, shows that at least in this locality the basaltic magma was passing to a phase more acidic, *i.e.*, to a later effusive stage and this stage was followed by a temporary cessation in the outpour of the lava as represented by the overlying fresh-water series.